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A SURVEY OF NAVAL AIRCRAFT CRASH ENVIRONMENTS WITH EMPHASIS ON STRUCTURAL RESPONSE

Dynamic Science 1500-71-43

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OFFICE OF NAVAL RESEARCH
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EXECUTIVE SUMMARY

AIRCRAFT CRASH SURVIVABILITY

Aircraft crashes are generally categorized as minor, survivable, or unsurvivable. The aircraft is normally not damaged substantially in a minor accident and few serious injuries occur.

The survivable accident is an accident in which the impact forces are sufficient to substantially damage and perhaps even destroy the aircraft, but the loadings which the occupants experience are within human tolerance limits and a protective shell is maintained around the occupants. The lower limit usually placed on the survivable accident category is that at least one of the occupants receives major injuries. Survivable accidents are of major interest because the severity of these accidents approaches the capability of the aircraft to provide occupant protection. The many fatalities and serious injuries occurring in these accidents could be avoided by use of adequate restraint and seating systems and by reducing the potential hazards inside the aircraft. Further study of these crashes provides evidence of the weak points and crush characteristics of the airframe and subcomponents, thus providing the knowledge whereby crashworthiness can be improved and survivability limits can be raised.

The unsurvivable accident is of minor interest in crashworthiness research because, even though the actual failure modes are sometimes quite apparent, the loads are too severe for the human body to withstand, or the loads are so high that the aircraft structural strength is not sufficient to maintain a liveable volume for the occupant. The primary purposes of crashworthiness research are to raise both the upper and lower limits of the survivable accident category and to minimize injuries within this category.

RESULTS OF THE STUDY

Results of this study indicate that helicopters provide the greatest potential for improvement in crash survival among current Naval aircraft. The primary reason for this finding is that more people are involved in helicopter crashes due to a lack of airborne escape systems which other aircraft possess, particularly high-performance jets. Of 2,081 occupants involved in the crashes studied (those crashes occurring since January 1969 in which the aircraft received substantial damage with occupants aboard), 1,039 were aboard helicopters, 597 were in propeller-driven aircraft, and 445 occupied high-performance jet aircraft. A total of 273 occupants received non-fatal injuries in the helicopter accidents compared to 23 in jets and 68 in propeller-driven aircraft. The most important fact is that 66 were killed in survivable helicopter accidents compared to 4 deaths which occurred in survivable jet aircraft accidents and 36 fatalities in survivable non-jet fixed-wing aircraft crashes.

INJURY PATTERNS

Injury patterns were developed from injuries which occurred in the surveyed accidents. The resulting patterns indicate the highest injury incidences to leg, head, and arm body areas. Three-fourths of all injuries sustained in Naval helicopters occur to these body portions. Leg injuries are the most frequent (28.7 percent). This is an indication that much more attention should be paid to the design of rudder pedals and padding of the area occupied by the legs Sharp and rigid lower edges of the instrument panel also cause many pilot leg injuries. In an interview with crash survivors, a pilot stated that the compound leg fractures he sustained were the result of the electronics compartment in the nose of his SH-3A rolling up and trapping his legs upon impact.

Head injuries account for 26.7 percent of all injuries in helicopter accidents, and in one severe Naval transport accident

77 percent of the 31 occupants received head injuries. These statistics indicate a need for improvement of the restraint systems, especially shoulder harnesses and helmets that are now in use.

Along with improvement of these systems, special care is necessary to design systems that are easy to use and comfortable. This was emphatically highlighted in an interview with a jet fighter pilot who stated that he would rather wear a cloth helmet than his current helmet because its bulkiness and weight puts a tremendous load on the head and neck in violent maneuvers. An 8-pound helmet, for example, weighs 48 pounds in a 6G pullout from a dive.

The Navy injury patterns were compared with injury patterns developed for Army and Air Force aircraft accidents as well as Civil aviation injury patterns; the general trends were the same.

FATALITY CAUSES

Post-crash survival problems accounted for over 95 percent of the fatalities that occurred in water impacts of Navy helicopters in the survey period. Of 42 fatalities in these accidents, 23 drowned, 16 were lost at sea, 1 was caused by fire, and only 2 were directly attributed to impact trauma. Survivors of helicopter water impacts related a multitude of problems they encountered which no doubt contributed to these statistics. A big factor is the tendency of helicopters to roll in water as soon as the rotor is stopped. This is because of the high center of gravity caused by heavy masses (engines, transmissions, etc.) in the upper portions of these aircraft. After the helicopter rolls, reduced visibility makes it difficult to find the escape hatches. Water or impact actuated cabin lights were suggested. One survivor complained that the soundproofing pads unsnap in severe impacts and entrap survivors. A locking snap could be used to alleviate this problem. Egress difficulty is also encountered in a partially water filled and inverted cockpit. Diving to exit submerged escape hatches, difficult in the confined space of a cockpit, is further complicated by the bulkiness and bouyancy of present life vests even before they have been inflated. Escape hatches in the bottom of the aircraft may be necessary.

In land helicopter impacts during the survey period, there were 72 fatalities directly attributed to impact forces, 16 of them in survivable accidents. Fire is the most dangerous post-crash survival factor in land impacts; 29 fatalities were caused by fire. More crushable structure to decrease impact loads exerted on occupants and components, energy-absorbing seats, and crashworthy fuel systems are means of lessening these problems.

Three persons were killed by rotor blade strikes in the land helicopter accidents. This seems to be a lower incidence than indicated by Army accident experience in which USABAAR found rotor blade penetration occurs in 1 of 8 accidents and transmission penetration into occupiable volume occurs in 1 of 4 accidents. Interviews with survivors of Naval helicopter accidents indicated intrusion of transmission into occupiable space was fairly rare although some noted minor displacement. Transmission displacement and rotor blade strikes are much less frequent in helicopters procured to the more stringent Navy specifications.

IMPACT VELOCITY ESTIMATES

Impact velocity estimates may be used to determine the amount of kinetic energy that aircraft structure is required to absorb in an accident. If the stopping distance is also known, G loadings that the occupants must withstand may be calculated. Unfortunately, this type of information is not generally contained in present Navy accident reports, and the report form should be changed to request the specific information desired.

Information that could be gleaned from the narratives was used to estimate the longitudinal and vertical impact velocities for severe but survivable accidents in the survey period. Cumulative frequency curves for impact velocities were constructed for both land and water helicopter impacts. As expected, much higher longitudinal velocities were survivable in water impacts than in land impacts. The median impact velocities were 22 and 38 ft/sec respectively for land and water impacts. The differences were not as marked for vertical velocities, with 22 ft/sec in water and 19 ft/sec on land being the median values. For comparison, the Army Crash Survival Design Guide shows 28 ft/sec for longitudinal and 24 ft/sec for vertical impact velocities as the median values for survivable accidents in helicopters and light fixed-wing aircraft. The Design Guide does not differentiate between land and water impacts.

Curves were also constructed on which combined impact velocities for the survivable helicopter accidents were plotted for land and water impacts. Superimposed upon the curves were regions designated as survivable, marginally survivable, and unsurvivable taken from the Army Design Guide. A significant fact emerged from this process - several of the H-46 and H-53 accidents fell in the range previously considered unsurvivable. Thus, it is recommended that designers take note of the fact that the newer aircraft procured to more stringent specifications are raising the upper limit of the survivable accident. It seems reasonable that more demanding structural requirements would raise this limit even more.

For survivable fixed-wing aircraft accidents, the longitudinal impact velocities are much higher, and the vertical impact velocities are lower than in helicopters as would be expected. This is the reason that long crushable noses have been recommended in the past in addition to keeping the occupants behind heavy masses such as the engines. A good example of the consequences of not doing this is contained in the report in a photograph of a crashed OV-10A. The OV-10A has a high wing from which are suspended the occupant cabin and twin engines. However, the occupants are well forward of the engines with virtually no crushable material in front of them. The picture shows the remains of the aircraft with the wing still intact and the occupant cabin completely crushed.

IMPACT TERRAIN EFFECTS

Death rates per major accident were calculated for the various types of aircraft surveyed. Within each category of aircraft, the death rates for both flight decks and runways were the lowest. The death rates were highest for water impacts of attack, fighter, and cargo aircraft. For helicopters, the highest death rates occurred in tree impacts. The reasons for low death rates on flight decks and runways are that most of these accidents are takeoff and landing accidents at lower speeds with rescue crews and emergency medical treatment in close proximity. Indications are that many of the water impacts in fixed-wing aircraft occur at cruising speed or greater due to pilot disorientation. The high death rates for helicopter tree impacts were surprising because of an apparent conflict with a technique suggested for Army use. An Army writer suggests that, when a crash becomes inevitable, a pilot should attempt to settle into trees, using them as an energy absorber.

In one severe EC-121M accident on land only 8 of the 31 occupants survived the crash. These survivors were all in aft facing seats in central and rear portions of the aircraft. In a crash, the aft facing seat is most desirable because the impact loadings are spread over the entire body and restraint is really only necessary to keep the occupant in the seat and prevent him from rebounding.

EXISTING AIRCRAFT WEAKNESSES

Interviews with survivors, witnesses, and investigators of Naval aircraft accidents also brought out certain specific weaknesses in existing aircraft. These include:

- Seat retention is not adequate in H-1 and H-3 helicopters in accidents in which there is a fairly large longitudinal impact velocity component.

- The crew jump seats in the H-2 could cause severe spinal damage should the fabric fail on vertical impact because of the solid brace underneath.

- Cargo retention is inadequate in helicopters and some helicopter occupants are being trapped and crushed by shifting cargo in accidents.

- Lateral strength of the cockpit in the T-28 trainer is inadequate. A suggested retrofit method of strengthening it is to insert a cross brace between the front and rear seats. One witness related an accident in which the cockpit narrowed 6 inches in a hard landing.

CONCLUDING REMARKS

Two major benefits can be realized from research of the type reported herein. The first is the determination of design criteria for future aircraft, and the second is determination of needed retrofits for existing aircraft. Aircraft designers need to know how much energy their aircraft may be required to absorb in a crash situation in order to limit the loads on the occupants. A basis for the determination of this energy is the upper limit of impact variables for present survivable accidents. To this end, cumulative frequency curves were constructed for impact velocities in present Naval aircraft. Although the velocities estimated from narrative information in present accident reports were comparable to existing data in the Crash Survival Design Guide, it is felt that better estimates could be made by on-the-scene accident investigators if there were specific requests for the needed information. In the present study it was not possible to determine the decelerative loadings experienced by the occupants of the crashes because information concerning gouge and skid patterns and structural deformations of the aircraft was not available. Thus, it is recommended that the accident report form used by the Navy be modified to gather the data necessary to establish crash loads for future use.

The fact that 95 percent of the fatalities which occurred in water impacts of helicopters were due not to impact forces above human tolerance as might be expected but rather were due to post-crash survival problems indicates the tremendous need for temporary flotation and anti-roll stability provisions for these aircraft. It also indicates the need for a critical look at the aircraft to determine the things which cause minor injuries (not dangerous to life in themselves) which slow the egress of the occupants and cause their death by drowning.

The fact that one-fourth of the fatalities which occur in survivable helicopter accidents are thermally caused indicates that all present helicopters that are not equipped with crashworthy fuel systems should be retrofitted. In accidents where fire occurs, as well as in the water impacts, the need to keep the occupants physically able to accomplish a rapid escape is of the utmost importance. This will require that present day aircraft be equipped with state-of-the-art seating and restraint systems. It will also require a study of component locations and mountings to determine injury potential. Minimization of major and minor injury in present survivable accidents will aid greatly in keeping the emergency preparedness of Naval aviation at a high level.

Finally, the study has shown that significant numbers of Naval personnel are being injured and lost in survivable crashes and in crashes which are near the upper limit of survivability.

Since a very large percentage of these casualties could be eliminated by improvement in the crashworthiness of these aircraft, results of the study emphasize the urgency of continued effort by the Navy in this area.

ACKNOWLEDGMENTS

The authors extend their appreciation to Dr. Nicholas Perrone of the Office of Naval Research for initiating and supporting this effort and for providing helpful suggestions in the preparation of the final report. Also, appreciation is extended to the various Naval facilities and organizations contacted for their cooperation and assistance in gathering the necessary data.

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INTRODUCTION

Until recently, the emphasis in aircraft accident investigations has been placed on finding causes in attempts to prevent similar occurrences. Military and civil aviation have benefitted greatly from this effort. However, accidents will probably never be completely eliminated and, for this reason, efforts spent on improving the crashworthiness of aircraft and the survivability of aircraft crashes are easily justified.

The survivability/crashworthiness of aircraft crashes can be improved by appropriate structural modifications.[1*] The most feasible method of determining appropriate structural modifications is through study of past crashes to evaluate structural performance and determine probable impact speeds and attitudes, injury patterns, and the typical crash environment (water, hard ground, mud, runway, mountains, etc.). The U. S. Army began a long range program to study aircraft safety and survivability characteristics in 1960. The results of many individual crashworthiness improvement programs were integrated into the Crash Survival Design Guide[2] which provides valuable information and guidance for use by designers involved in designing aircraft for survivability.

The information contained in the Design Guide applies in general to all aviation, but specific information is necessary to solve specific problems. For example, the aircraft carrier environment is almost totally a Navy problem and the incidence of water impacts is much more frequent for Naval aircraft than for other military aircraft. For these reasons, it was deemed appropriate that the present program be conducted to obtain "A Survey of Naval Aircraft Crash Environments With Emphasis on Structural Response".

*Superscript numbers denote references which are listed on page 66.

The purpose of the present program was to conduct research in survival aspects of Naval aircraft crashes in order to identify areas for needed improvement in structural design. The results of the research are presented in this report as:

- Approach to the Problem
- Generated Data Base
- Analysis and Discussion
- Conclusions
- Recommendations

APPROACH TO THE PROBLEM

The data base generated for analytical purposes in this program was based on a combination of published literature, documented Naval aircraft crash data, and firsthand information obtained through interviews with Naval personnel and inspection of aircraft at Naval facilities. The content of the data base is discussed in the next section. The approach used to establish the data base and the methods of analysis are discussed herein.

The Defense Documentation Center was requested to compile a report bibliography and work unit summaries. When these were received, documents pertinent to the study were ordered and reviewed for pertinent information. The numerous reports generated by Dynamic Science on structural crashworthiness and crash injury research provided a valuable source of information for the study.

Documented crash data were obtained from the computerized data bank maintained at the Naval Safety Center in Norfolk, Virginia. The data search was limited to major accidents with occupants aboard during the impact. The type of information printed for each accident report was: date, time, location, aircraft model, extent of damage, mishap causes, mishap type, phase of operations, degree of injuries to occupants, and a short narrative which rarely contained specific information relative to crash dynamics. In a few cases, the reports did provide limited information on altitude, speed, and maneuvers attempted or completed when the emergency occurred. Medical reports for all occupants of the selected accidents were also extracted from the data bank. Data available in the medical reports, besides the injuries sustained by the occupant, were the causes of the injury, duty function of the occupant, location of the occupant in the aircraft, method of escape (if any), the type of impact terrain, and a short narrative.

Firsthand data were obtained from interviews with Naval personnel during visits to several Naval facilities. Safety officers, accident investigators, accident survivors and witnesses, crash damage estimators, etc., were interviewed in an attempt to acquire all available data including information that was not available in the accident reports such as specifics on crash dynamics, amounts of deformation, seat retention, transmission displacement, and any structural inadequacies or survival problems. The salvage yard at NARF (Naval Air Rework Facility), North Island, California, was visited for a firsthand look at crash-damaged aircraft. Photographs were obtained of some of the damaged aircraft and are used to illustrate specific points in this report.

Analyses were performed mainly on the documented data obtained from the Naval Safety Center. The analogous U. S. Army facility, the U. S. Army Board for Aviation Accident Research (USABAAR), Fort Rucker, Alabama, was contacted to gain comparisons between the accident data requirements of the two Armed Services. Copies were obtained of the Army's new DA Form 2397 series (1 Sept 70) which is now used for Army aviation accident reports.

A search was made of the documented data to determine accidents of specific interest. These were accidents in which not all of the occupants were killed and at least one of the occupants suffered major (or fatal) injuries. These accidents may be used to define the present limits of survivable accidents in Naval aircraft and the crashworthiness of the aircraft involved since they are, in general, as serious as is possible without being non-survivable.

The firsthand data and literature review results were used to amplify the documented data and to compare with trends established in the Navy data obtained from the Safety Center.

GENERATED DATA BASE

The generated data base, as explained previously, consists of the information generated in the literature search, the documented crash data, and the firsthand data gained through interviews with Naval personnel and inspection of crash-damaged Naval aircraft. The content of the data base is discussed in this section.

DEFINITIONS

The following terms are defined according to the intent and manner of their use in this report.

1. Accident: An unplanned event in which an aircraft sustains damage incident to flight operations. Use of the word "accident" refers to an aircraft accident in this report unless specified otherwise.

2. Major Accident: An accident in which the aircraft receives at least substantial damage. All the accidents in the documented data base were major accidents.

3. Non-survivable Accident: An accident in which the G-loadings were above the limits of human tolerance or in which a liveable volume was not maintained for the occupants of the aircraft.

4. Substantial Damage: A determination made according to the number of man-hours required for repair of the aircraft. The value differs for various aircraft and is determined according to OPNAV Instruction P3750.6F for U. S. Navy/Marine aircraft[3] and AR 385-40 for U. S. Army aircraft.[4]

5. Survivable Accident: An accident in which a liveable volume was maintained for the occupants and the G-loadings were not above the limits of human tolerance. In the context in which it is used in this report, it means a serious accident, usually in which one or more occupants received major (or fatal) injuries but not all were killed.

REVIEW OF LITERATURE

A large portion of the state-of-the-art literature on aircraft structural crashworthiness (especially for helicopters) has been developed by and for the U. S. Army. Much of the information thus generated is contained in the Crash Survival Design Guide[2] which is authored and periodically updated by Dynamic Science for the Army. The guide presents, in a condensed form, the data, design techniques, and design criteria that are presently available in eight areas:

1. Aircraft Crash Kinematics and Survival Envelopes
2. Airframe Crashworthiness
3. Aircraft Seats and Litters (Crew and Troop/Passenger)
4. Restraint Systems (Crew, Troop/Passenger, and Cargo)
5. Occupant Environment
6. Aircraft Ancillary Equipment Stowage
7. Emergency Escape Provisions
8. Postcrash Fire

Two recent papers by J. L. Haley, Jr., of USABAAR[5,6] concern specific methods of designing for impact survival in helicopters. Desjardins[7] surveyed the field of aircraft crashworthiness and discussed areas of potential improvement in the most recent paper in the literature.

An important work which considers the things to look for when evaluating the crashworthiness of a crashed aircraft is the Crash Survival Investigation Textbook.[8] Methods of estimating crash dynamics are found in this text, as well as in the Navy's Handbook for Aircraft Accident Investigators.[9]

Causes of death in Navy/Marine and Army helicopters from 1952-1968 and methods of eliminating them is the subject of a report by Senderhoff.[10]

Structural design requirements for Navy helicopters are given in AR-56.[11]

A pertinent bibliography follows the references at the end of this report.

DOCUMENTED DATA

The documented data used in the compilation of this report consisted of 611 accident reports for which computer summaries were obtained from the data bank at the Naval Safety Center in Norfolk, Virginia. Computerized summaries of the medical reports for personnel who occupied the aircraft involved in these accidents were also obtained from the same source. Accidents included in the survey cover the period from January 1969 to approximately May 1971.

The following criteria were used to select the accidents of interest:

1. The accident resulted in aircraft destruction or substantial damage.

2. The accident occurred in the takeoff, landing, or in-flight phase of operations. Ground accidents were excluded from the data search.

3. Some occupants were involved in the crash. Accidents in which all occupants ejected or bailed out were excluded from the search.

The objectives of the study dictated the selection criteria. Accidents with less than substantial damage would probably not be indicative of the crashworthiness of the aircraft because the impact forces are considerably below both the human tolerances and the aircraft structural strength. Crashes with no occupants aboard (after ejection or bail-out) would not be indicative of survivability of the crash.

The accidents selected covered most of the current aircraft in the Navy's inventory. Table I lists the various types of aircraft included in the survey and gives the total number of accidents in the survey period which met the selection criteria for each type of aircraft. Table I also lists the number of relevant accidents for each type. The relevant accidents are mostly of the "survivable" category defined previously, and are accidents which it was felt would provide information on areas for crashworthiness improvement in Naval aircraft.

Pertinent information concerning the relevant accidents in the survey is contained in Table II. Information such as aircraft damage and accident type, phase of operations, and time of day was taken from the accident report summaries and injury information was taken from the medical report summaries. The remarks are significant items from the narratives of either

TABLE I. TOTAL AND RELEVANT NAVAL ACCIDENTS BY AIRCRAFT TYPE, JANUARY 1969 - MAY 1971 (APPROXIMATE)

Aircraft	Time Period Covered	No. of Accidents	Relevant Accidents	Aircraft	Time Period Covered	No. of Accidents	Relevant Accidents
A-1	Feb 25 69 - Sep 29 69	3	1	H-1	Jan 16 69 - Apr 7 71	70	15
A-3	Feb 13 69 - May 17 71	16	2	H-2	Mar 3 69 - Oct 14 70	10	1
A-4	Jan 17 69 - May 16 71	80	2	H-3	Feb 8 [illegible] - Apr 27 71	18	3
A-5	Jan 20 69 - Apr 19 71	9	0	H-19	Jan 2 69 - Mar 26 69	2	0
A-6	Mar 26 69 - Mar 24 71	18	1	H-34	Jan 15 69 - Jun 15 70	24	5
A-7	Jan 3 69 - Apr 17 71	41	0	H-46	Jan 10 69 - Apr 27 71	40	6
				H-53	Mar 19 69 - Apr 21 71	15	5
F-4	Jan 7 69 - May 2 71	56	1	H-57	Feb 19 70 - Nov 16 70	4	0
F-8	Jan 8 69 - May 16 71	60	3				
F-9	Mar 21 69 - Dec 1 70	17	1	O-1	Sep 7 69	1	0
F-10	Mar 28 69	1	0				
F-111	Oct 6 69	1	0	P-2	Feb 11 69 - Sep 25 69	7	2
				P-3	Feb 13 69 - Aug 3 70	4	0
C-1	Mar 22 69 - Apr 26 71	5	1				
C-2	Oct 2 69 - Dec 15 70	2	0	S-2	Feb 12 69 - Feb 17 71	21	1
C-45	Apr 24 69 - Nov 17 70	5	2				
C-47	Apr 29 69 - Jul 25 69	3	2	T-1	Jan 16 69 - Jul 8 70	3	0
C-54	Jun 5 69 - Jul 30 69	2	0	T-2	Sep 12 69 - Feb 18 71	6	0
C-117	Jan 12 69 - Dec 13 70	4	0	T-28	Jan 29 69 - Apr 14 71	23	1
C-118	Apr 25 71	1	0	T-33	Mar 5 69 - Jun 9 70	6	0
C-119	Feb 28 71	1	0	T-34	Oct 10 69 - Jul 29 70	3	1
C-121	Mar 16 70 - Oct 8 70	2	1				
C-130	Jul 30 70 - Aug 1 70	2	0	U-11	Apr 29 71	1	1
E-1	Feb 18 69 - Feb 28 71	13	0	OV-10	May 6 69 - Jan 13 71	6	0
E-2	Jan 4 69 - Apr 2 71	4	0				
				X-26	Mar 6 71	1	0

TABLE II. NAVAL AIRCRAFT ACCIDENTS, JANUARY 1969 - MAY 1971 (APPROXIMATELY)

No.	Aircraft Type and Aircraft Accident Report No.	Aircraft Damage* and Accident Type	Phase	Time	Terrain	Injuries Type F	MA	MI	N	Injuries Description	Cause	Remarks	Impact Velocity (Est ft/sec) Long.	Vert.
1	A-1E, 69022510101	A, Collision ground	In flight from field	Day	Deep snow	0	2	0	0	MA-Compression 12th thoracic and 1st lumbar vertebrae MA-Compression of 1st lumbar vertebra	All Impact	Forced landing in mountains, snow impact	80	20
2	KA-3B 70021810101	A, Stall/spin collision ground	Waveoff	Day	Soft ground	1	2	0	0	F-Fractures of total skull and 4th cervical vertebra MA-Fractures of skull and both legs MA-Knee, leg, skull fractures	All Struck cockpit structure	Occupants hurled from aircraft, securely restrained in seats; fatality not wearing helmet properly	220	77
3	EA-3B, 70022610401	A, Collision water	Takeoff, carrier catapult	Day	Open sea	3	1	0	0	F-Three lost at sea MA-Lacerations of total skull and broken left leg	- Impact	Impacted water level, flipped over and sank; survivor's helmet prevented further injury	150	60
4	TA-4F, 69020810101	A, Hard landing	Landing-field	Day	Hard ground	0	1	1	0	MA-Burns of total skull, left face, etc. MI-Bilateral leg burns, burns of arm, wrist, etc.	All Fire/heat	High sink rate, burst into fire upon impact with ground	250	17
5	A-4E, 71020410101	A, Ground swerve	Landing	Day	Not indicated	0	1	0	0	-	-	No narrative	150	0
6	A-6A, 69041910301	A, Bird ingestion	Takeoff from field	Day	Mud	0	1	1	0	MA-Anoxia from chemical foam ingestion MI-Chemical burns of both eyes	Rescue operations	Overran, inverted, and trapped crew	200	0
7	F-4J, 70053010101	C, Hard landing	Landing on carrier	Day	Flight deck	0	0	1	1	MI-Lumbosacral strain	Impact	Harness straps to be checked for excessive play	200	15
8	F-8H, 69011110301	C, Airframe failure	Landing on carrier	Day	Flight deck	0	0	1	0	MI-Neck strain	Impact	Nose landing gear collapsed, aircraft, came to rest on fuselage	200	0

*A: Total Destruction C: Substantial Damage

TABLE II. NAVAL AIRCRAFT ACCIDENTS, JANUARY 1969 - MAY 1971 (APPROXIMATELY) (CONTD)

No.	Aircraft Type and Aircraft Accident Report No.	Aircraft Damage* and Accident Type	Phase	Time	Terrain	Injuries						Remarks	Impact Velocity (Est ft/sec)	
						Type				Description	Cause		Long.	Vert.
						F	MA	MI	N					
9	RF-8G, 69012810101	C, Landing gear collapse	Takeoff from field	Day	Not indicated	0	0	1	0	MI-Left elbow abrasion, etc.	Cabin structure	Aircraft skidded on runway, premature landing gear retraction	180	0
10	F-8J, 69022210201	C, Overrun	Landing-field	Day	Not indicated	0	0	1	0	MI-Left side face abrasion, etc.	Impact	Overran runway 3,800 feet	240	10
11	TF-9J, 69061810201	A, Collision ground	Takeoff from field	Night	Hard ground	0	1	0	0	MA-Compression of 12th thoracic vertebra	Impact	Impacted just after liftoff	190	20
12	C-1A, 69071010501	A, Collision water	Takeoff, carrier catapult	Night	Open sea	1	1	0	0	MA-Compound fracture of left leg, etc.	Impact	Aircraft and crewman lost at sea	230	30
13	UC-45J, 70032210101	A, Collision ground	In flight from field	Day	Hard ground	1	2	0	0	F-Burns over 90% of body	Thermal	Impacted trees and burst into flames	70	70
										MA-Abdominal hemorrhage, etc.	Restraint			
										MA-Facial lacerations, etc.	Other cockpit structure			
14	UC-45J, 70111710201	A, Collision ground	In flight from field	Day	Dense woods	0	3	0	0	3MA-Multiple burns	Thermal	Impacted trees, rolled inverted, and burned	50	70
15	C-47H, 69042910301	A, Collision ground	Waveoff from field	Day	Dense woods	0	1	2	1	MA-Compression of 1st and 2nd lumbar vertabrae, etc.	Impact	Impacted trees, MA not properly restrained	88	12
										MI-Thorax contusion	Restraint			
										MI-Skull lacerations	Impact			
16	TC-47K, 69050810201	A, Ground swerve	Landing-field	Day	Hard ground	0	2	1	0	MA-Skull lacerations, etc.	External strike	Cartwheeled and burst into fire	75	10
										MA-Skull concussion, etc.	Cockpit structure			
										MI-Thorax contusion, etc.	Impact			
17	EC-121M, 70031610101	A, Stall, collision ground	Waveoff from field	Day	Hard ground	23	6	1	1	All-Impact injuries and burns	Impact/ thermal	Restraint questioned by Medical Officer's Report	145	15

*A: Total Destruction C: Substantial Damage

TABLE II. NAVAL AIRCRAFT ACCIDENTS, JANUARY 1969 - MAY 1971 (APPROXIMATELY) (CONTD)

No.	Aircraft Type and Aircraft Accident Report No.	Aircraft Damage* and Accident Type	Phase	Time	Terrain	Injuries Type F	MA	MI	N	Injuries Description	Injuries Cause	Remarks	Impact Velocity (Est ft/sec) Long.	Vert.
18	UH-1E, 69012610201	, Hard landing	Landing-field	Night	Hard ground	0	2	2	0	MA-Skull concussion, etc.	Impact	Use of helmets and restraint systems inadequate	88	35
										MA-Knee derangement	Impact			
										MI-Facial laceration	Equipment Strike			
										MI-Elbow laceration	Impact			
19	UH-1B, 69042310201	A, Collision power line	In flight from field	Night	Hard ground	1	1	2	0	F-Burns	Thermal	Vertical drop; hit ground with left side low in nose-down attitude and burned	10	60
										MA-Burns	Thermal			
										MI-Knee contusion	Impact			
										MI-Leg contusion	Impact			
20	UH-1E, 69031410101	C, Hard landing	Takeoff from field	Day	Soft ground	0	0	2	2	2MI-Neck sprain	All Impact	Impact ground upright, need head rest	35	17
21	UH-1E, 69051810201	A, Collision ground	Autorotation, field	Day	Hard ground	0	2	2	0	MA-Compressed 8th thoracic vertebra	Impact	Rotor blades struck ground, transmission torn loose; high lateral G's	20	25
										MA-Leg and elbow lacerations	Cockpit Strikes			
										MI-Strained back	Impact			
										MI-Sprained sacrum coccyx	Impact			
22	UH-1E, 69061710201	A, Collision object/ground	Landing-field	Day	Hard ground	0	1	0	3	MA-Facial lacerations	Microphone and matting	Loose matting, inverted on impact	25	20
23	UH-1D, 69062510101	C, Collision ground	Autorotation, field	Day	Soft ground	0	1	1	0	MA-Fractured face	Control column	Both seats broke loose on impact	30	20
										MI-Strained back	Impact			
24	UH-1E, 69072510301	A, Collision ground	Landing-field	Day	Hard ground	0	1	3	0	MA-Compound leg fracture	Unattached equipment	Aircraft rolled down slope	10	15
										MI-Leg contusion	Unattached equipment			
										MI-Concussion; contusions	Struck canopy			
										MI-Skull laceration	-			

*A: Total Destruction C: Substantial Damage

TABLE II. NAVAL AIRCRAFT ACCIDENTS, JANUARY 1969 - MAY 1971 (APPROXIMATELY) (CONTD)

No.	Aircraft Type and Aircraft Accident Report No.	Aircraft Damage* and Accident Type	Phase	Time	Terrain	Injuries Type F	MA	MI	N	Injuries Description	Cause	Remarks	Impact Velocity (Est ft/sec) Long.	Vert.
25	UH-1B, 69081310101	A, Collision water	Takeoff from ship	Night	Open sea	1	1	2	0	F-Drowned	-	Aircraft flown into water, sank; 4th man drowned strapped in aircraft; seat retention problem	80	20
										MA-Facial lacerations and fracture	Dislodged equipment			
										MI-Leg abrasions, contusions	Impact			
										MI-Leg abrasions, facial lacerations	Impact			
26	UH-1B, 69091510201	A, Collision water	Takeoff from ship	Night	Deep water	2	2	0	0	2F-Drowned	All Impact	Aircraft flown into water 150 feet from takeoff point at 60-knots airspeed; drowning fatalities probably unconscious from impact	100	20
										MA-Facial lacerations and fracture				
										MA-Wrist dislocation, ankle fracture, etc.				
27	UH-1B, 69121410101	A, Collision water	In flight from field	Day	River	1	1	2	0	F-Drowned	All Impact	Airspeed 20-60 knots; right wing down, nose-low attitude; aircraft sank with crew trapped; restraint questioned	65	25
										MA-Leg laceration				
										MI-Facial laceration				
										MI-Facial contusion				
28	UH-1E, 69122210201	A, Collision ground	In flight from field	Day	Soft ground	0	2	2	0	MA-Compressive fracture of 3rd lumbar vertabra	Restraint and Impact	Aircraft impacted ground and rolled inverted	30	15
										MA-Leg fracture and arm abrasion	Other and Impact			
										MI-Facial contusion, etc.	Impact			
										MI-Leg abrasion	Cabin structure			
29	UH-1E, 70020910301	A, Collision trees/ground	Takeoff from field	Day	Trees	2	2	1	1	F-Transected thorax	All Impact	Crashed into trees and came to rest nose down; fatalities caused by flexion around belts; no harnesses	80	15
										F-Crushed thorax, etc.				
										MA-Fractured arm				
										MA-Fractured arm, comcompressive fracture of 1st, 2nd, and 3rd lumbar vertebrae				
										MI-Skull lacerations				

*A: Total Destruction C: Substantial Damage

TABLE II. NAVAL AIRCRAFT ACCIDENTS, JANUARY 1969 - MAY 1971 (APPROXIMATELY) (CONTD)

No.	Aircraft Type and Aircraft Accident Report No.	Aircraft Damage* and Accident Type	Phase	Time	Terrain	Injuries Type F	MA	MI	N	Injuries Description	Injuries Cause	Remarks	Impact Velocity (Est ft/sec) Long.	Vert.
30	UH-1E, 70031310201	A, Collision ground	In flight from field	Day	Shallow water	0	1	1	1	MA-Leg fracture, etc. MI-Skull lacerations, etc.	No data Cabin structure	Airspeed of 35 knots and level attitude; came to rest in 1-foot surf; aircraft flipped over	60	8
31	UH-1B, 71021710101	A, Collision water	In flight, sea	Day	Open sea	0	1	3	0	MA-Compressive fracture of 12th thoracic vertebra MI-Strained back MI-Strained neck MI-Strained neck	All Impact	Zero airspeed and rate of descent; settled straight into water with moderate impact and sank	2	20
32	UH-1B, 71040710201	A, Collision ground	Autorotation, field	Day	Hard ground	0	2	0	0	MA-Lumbar spine MA-Fractures	All impact	Aircraft came to rest inverted; pilots suspended by harnesses	40	30
33	UH-2C, 69081010301	A, Collision water	In flight from carrier	Day	Open sea	0	1	0	3	MA-Fractured arm	Cabin structure	Impacted 80°-90° left wing down; lost at sea	50	20
34	SH-3A, 69031710201	A, Collision water	In flight from field	Night	Shallow water	1	3	1	0	F-Drowned MA-Fractured leg and arm MA-Fractured hand, etc. MA-Fractured 6th lumbar vertebra, etc. MI-Lacerations, abrasions, etc.	Impact Structure Structure Impact Structure	Aircraft rolled inverted, burst into flames	200	15
35	SH-3A, 69062710201	A, Collision water	In flight from field	Night	Open sea	1	1	0	2	MA-Compressive fractures of 9th, 11th and 12th thoracic vertebrae	Impact	Violent, flat impact; inverted and sank	5	45
36	SH-3D, 69091810101	A, Collision ground	In flight from field	Day	Hard ground	0	3	0	1	2MA-Compressive fractures of 12th thoracic vertebra MA-Comminuted leg, etc.	All Impact	Aircraft impacted level.	20	20

*A: Total Destruction C: Substantial Damage

TABLE II. NAVAL AIRCRAFT ACCIDENTS, JANUARY 1969 - MAY 1971 (APPROXIMATELY) (CONTD)

No.	Aircraft Type and Aircraft Accident Report No.	Aircraft Damage* and Accident Type	Phase	Time	Terrain	Injuries: Type F	MA	MI	N	Injuries: Description	Cause	Remarks	Impact Velocity (Est ft/sec) Long.	Vert.
37	SH-34J, 69011510201	A, Collision ground	In flight from field	Dusk	Dense woods	1	1	1	0	F-Burns	Fire	Aircraft autorotated into trees, rolled over, and burst into flames	20	20
										MA-Leg burns	Fire			
										MI-Back abrasions, etc.	Impact			
38	UH-34D, 69013010101	A, Collision ground	In flight from field	Day	Soft ground	2	2	0	0	2F-Struck by rotor blade	Rotor blade	Impacted in flat attitude and burst into flames	10	25
										2MA-Strained back	Impact			
39	UH-34D, 69062710201	A, Collision cables	Landing-field	Night	Hard ground	1	1	0	0	F-Burns	All Fire	Impacted ground, rolled over, and burst into flames	50	20
										MA-Burns				
40	UH-34J, 69071010401	A, Collision ground	No data	Day	Soft ground	1	1	1	0	F-Fractured thorax, etc.	All Impact	Impacted ground in inverted position	10	35
										MA-Fractured skull, etc.				
										MI-Internal hemorrhage				
41	LH-34D, 69111910101	A, Collision ground	In flight from field	Day	Deep snow	2	4	2	0	2F-Carbonized	Fire	Power failure, aft section of aircraft exploded in flame	15	10
										MA-Elbow contusion	Impact			
										MA-Compressive fracture of 5th thoracic vertebra, etc.	Impact			
										MA-Face and hand burns	Fire			
										MA-Hand and thorax burns	Fire			
										MI-Knee abrasion, facial burn	Fire			
										MI-Leg burns	Fire			
42	CH-46A, 69030110401	A, Collision water	In flight from field	Day	River	1	1	1	0	F-Drowned	All Impact	Landed upright in 5-feet of water; armored seats broke loose on impact; copilot knocked unconscious and drowned	200	25
										MA-Leg, face, and arm lacerations				
										MI-Hand laceration				

*A: Total Destruction C: Substantial Damage

TABLE II. NAVAL AIRCRAFT ACCIDENTS, JANUARY 1969 - MAY 1971 (APPROXIMATELY) (CONTD)

No.	Aircraft Type and Aircraft Accident Report No.	Aircraft Damage* and Accident Type	Phase	Time	Terrain	Injuries: Type P	MA	MI	N	Description	Cause	Remarks	Impact Velocity (Est ft/sec) Long.	Vert.
43	CH-46D, 69060710402	A, Collision ground	Takeoff from field	Day	Trees	2	1	1	0	P-Crushed skull P-Burns MA-Burns, leg laceration MI-Facial lacerations, etc.	Impact Fire Fire and impact Impact	Aircraft struck side of hill, rolled down slope, and burst into flames; impact fatality's seat broke loose, thrown from aircraft	25	10
44	CH-46A, 69071610201	A, Collision water	In flight from carrier	Day	Open sea	0	2	1	0	MA-Fractured wrist, etc. MA-Fractured ribs MI-Buttock contusion	All cockpit and cabin structure	On impact, aircraft rolled inverted and sank	30	30
45	CH-46D, 70030710101	A, Collision water	In flight from field	Day	Open sea	4	1	0	0	4P-Drowned, lost at sea MA-Compressive fracture of 5th thoracic vertebra, etc.	 Impact	Impacted water, nose up	40	33
46	CH-46D, 70082510301	A, Collision ground	Landing-field	Day	Steep slope	0	2	1	4	MA-Fractured arm MA-No Data MI-Facial lacerations, etc.	No data Cabin structure	Caught wire, punctured fuel cell, and burned	28	15
47	CH-46D, 71041910101	A, Fire-collision water	In flight from field	Day	Shallow water	3	0	2	0	P-Internal organs ruptured, etc. P-Burns, etc. P-Crushed chest, etc. MI-Perforated foot MI-Rib contusion	Impact Fire Impact Impact Cabin structure	Aircraft impacted water slightly nose low and disintegrated into 3 sections	70	30
48	CH-53A, 69040910201	A, Collision ammo pallet	In flight from field	Day	Hard ground	0	3	1	0	MA-Burned arm, buttocks MA-Foot fracture MA-Skull compression, etc. MI-Skull laceration	Fire No data Impact Impact	Aircraft impacted ground, rolled over, and burst into flame	20	12

*A: Total Destruction C: Substantial Damage

TABLE II. NAVAL AIRCRAFT ACCIDENTS, JANUARY 1969 - MAY 1971 (APPROXIMATELY) (CONTD)

No.	Aircraft Type and Aircraft Accident Report No.	Aircraft Damage* and Accident Type	Phase	Time	Terrain	Injuries: Type F	MA	MI	N	Injuries: Description	Injuries: Cause	Remarks	Impact Velocity (Est ft/sec) Long.	Vert.
49	CH-53A, 69110110101	A, Collision water	In flight from field	Night	Deep water	4	1	0	0	4F-Drowned, lost at sea	All Impact	Engine exploded on impact with water; MA released restraints	170	70
										MA-Dislocated pelvis, etc.				
50	CH-53A, 70050410101	A, Collision ground	Landing-field	Day	No data	1	3	1	0	F-Fractured skull, etc.	Impact	Aircraft impacted ground, rolled down slope, and burst into flames	60	30
										MA-Multiple burns, fractured ankle, etc.	Fire and impact			
										MA-Multiple burns	Fire			
										MA-Multiple burns	Fire			
										MI-Burned hand, laceration	Fire and impact			
51	CH-53A, 70070610101	C, Collision ground	In flight from field	Dusk	Hard ground	0	2	0	1	MA-Sprained back	All Impact	Autorotation to hard landing on belly	60	35
										MA-Facial compression				
52	CH-53D, 70102610101	A, Collision ground	Takeoff from field	Dusk	Marsh/ mud	1	2	3	0	F-Multiple	Rotor blade strike	Descending right turn impact, fire	80	30
										MA-Compound arm fracture	Impact			
										MA-Compound leg fracture, etc.	Rotor blade strike			
										MI-Lacerated arm	Impact			
										MI-Skull lacerations, etc.	Impact			
										MI-Facial lacerations	Impact			

*A: Total Destruction C: Substantial Damage

TABLE II. NAVAL AIRCRAFT ACCIDENTS, JANUARY 1969 - MAY 1971 (APPROXIMATELY) (CONTD)

No.	Aircraft Type and Aircraft Accident Report No.	Aircraft Damage* and Accident Type	Phase	Time	Terrain	Injuries: Type P	Injuries: Type MA	Injuries: Type MI	Injuries: Type N	Injuries: Description	Injuries: Cause	Remarks	Impact Velocity (Est ft/sec) Long.	Impact Velocity (Est ft/sec) Vert.
53	SP-2H, 69030110503	A, Collision water	In flight from field	Day	Open sea	0	1	7	1	MA-Skull fracture, etc. MI-Shoulder abrasions, etc. MI-Leg laceration MI-Leg contusion MI-Leg abrasion MI-Neck abrasion, etc. MI-Elbow abrasion MI-Facial lacerations, etc.	All Impact	Aircraft ditched into sea, level attitude; MA result of lap belt failure	100	10
54	SP-2H, 69050410201	A, Collision ground	Waveoff	Day	Hard ground	0	1	4	0	MA-Compressive fracture of 9th thoracic vertebra, etc. MI-Leg lacerations MI-Ankle abrasion MI-Facial contusions, etc. MI-Rib contusion	All Impact	Impacted ground and burst into flames, MA sustained by crewmen standing on deck	80	15
55	UH-2A, 69072810131	C, Ground swerve	Landing	Day	Soft ground	0	1	1	2	MA-Comminuted leg MI-Leg abrasion	Impact Struck hatch	Aircraft hydroplaned and ground looped; prop hit pilot's leg	100	0
56	T-28B, 70110710101	A, Collision ground	Takeoff from field	Day	Hard ground	1	1	0	0	P-Crushed chest, etc. MA-Leg fracture, etc.	All other cockpit structure	Pilot's shoulder harness anchorage point failed	80	80
57	T-34B, 70031610301	A, Collision ground	In flight from field	Day	Soft ground	0	2	0	0	MA-Comminuted leg, etc. MA-Skull concussion, etc.	All Impact	Aircraft stalled and rolled; nose down impact	85	30

*A: Total Destruction C: Substantial Damage

TABLE II. NAVAL AIRCRAFT ACCIDENTS, JANUARY 1969 - MAY 1971 (APPROXIMATELY) (CONTD)

No.	Aircraft Type and Aircraft Accident Report No.	Aircraft Damage* and Accident Type	Phase	Time	Terrain	Injuries: Type F	MA	MI	N	Injuries: Description	Injuries: Cause	Remarks	Impact Velocity (Est ft/sec): Long.	Vert.
58	U-11A, 71042910101	A, Collision ground	In flight from field	Day	Soft ground	0	1	2	0	MA-Skull concussion, etc.	Control column impact	Impacted in plowed field; no shoulder restraint; one seat broke loose	170	5
										MI-Facial lacerations, etc.	Control column impact			
										MI-Leg lacerations, etc.	Impact			
59	T-28B 69092610201	A, Collision ground	Landing field	Day	Soft ground	1	0	1	0	P-Multiple fatal injuries	Impact	Stalled on approach, cartwheeled and broke in half	90	50
										MI-Sprained ankle	Rudder pedal			

*A: Total Destruction C: Substantial Damage

the accident or medical report. Impact velocity information was usually not given directly, but was estimated from the phase of operations, knowledge of the maneuvers just completed, normal operating and stall speeds of the aircraft, etc. Although the impact speeds are not documented information, they were estimated and included in the table to allow the reader to develop an idea of the correlation between impact speed, aircraft damage, and occupant injury.

The data from all 611 accidents were used to establish the typical crash environment, injury patterns, causes of death, etc. Tables III and IV summarize occupant survival and crash environments for the accidents used in the survey.

TABLE III. OCCUPANT SURVIVAL SUMMARY - NAVAL AIRCRAFT CRASHES JANUARY 1969 - MAY 1971 (APPROXIMATELY)

Type Aircraft	All Killed Accidents		None Hurt Accidents		Accidents With Injuries					
	No.	Total Occupants	No.	Total Occupants	No.	F	MA	MI	N	Total Occupants
Attack	46	58	112	162	9	4	9	6	2	21
Cargo	[illegible]	40	16	129	5	29	18	9	77	133
Early Warning	3	14	13	43	1	2	0	0	2	4
Fighter	42	46	85	120	8	0	1	7	4	12
Helicopter	15	81	77	376	91	66	68	205	243	582
Observation	0	0	1	2	0	0	0	0	0	0
Patrol	3	23	1	13	5	1	4	22	19	46
Antisubmarine	7	31	11	34	3	1	4	3	5	13
Trainer	14	20	21	35	[illegible]	2	3	5	1	11
Utility	0	0	0	0	1	[illegible]	1	2	0	3
V/STOL	2	3	4	7	0	0	0	0	0	0
Research	0	3	0	0	1	1	0	0	1	2
Propeller	26	113	61	273	25	36	29	39	165	269
Jet	92	124	205	388	17	4	8	15	6	33
Helicopter	15	81	77	376	91	66	68	205	243	582
TOTALS	133	320	343	937	133	106	105	259	356	826
Percent*	22.3	11.4	56.2	41.9	21.8	5.1	5.1	12.6	17.0	39.6

*Note: Accident percentages based on 611 total accidents.
Occupant percentages based on 2,083 total occupants.

Type Aircraft	Total Acci-dents	All Fatal		None Hurt		Other Accidents	
		Water	Land	Water	Land	Water	Land
Attack	167	25	21	58	54	2	7
Cargo	27	2	1	1	15	1	7
Early Warning	17	1	2	9	4	1	0
Fighter	135	22	20	48	37		6
Helicopter	183	1	14	27	50	34	57
Observation	1	0	0	0	1	0	0
Patrol	11	0	3	0	3	2	3
Antisubmarine	21	3	4	1	10	2	1
Trainer	41	3	11	0	21	1	5
Utility	1	0	0	0	0	0	1
V/STOL	6	0	2	0	4	0	0
Research	1	0	0	0	0	0	1
Propeller	114	7	21	13	48	7	18
Jet	314	49	43	104	101	4	13
Helicopter	183	1	14	27	50	34	57
TOTALS	611	57	78	144	199	45	88
Percent	100.0	9.2	12.8	23.6	32.6	7.4	14.4

TABLE IV. CRASH ENVIRONMENT SUMMARY - NAVAL AIRCRAFT ACCIDENTS JANUARY 1969 - MAY 1971 (APPROXIMATELY)

Note: Water environment includes carrier vehicle accidents.

For each category of Naval aircraft surveyed, Table III presents accidents in which all were killed, accidents in which none were hurt, and accidents with injuries of varying degrees to some occupants. The relevant accidents in Table II were taken from the third category (accidents with injuries) with further stipulation that at least one of the injured received major (or fatal) injuries. Within the survey period, 56.1 percent of the Naval aircraft crashes studied were accidents in which none of the occupants were injured even though the aircraft received at least substantial (C) damage. In spite of the fact that 45 percent of the total occupants involved in crashes within the survey period were in these accidents, the accidents were of no further interest because the G loadings obviously did not exceed a tolerable level and the occupant's survival was not threatened by a major decrease in his occupiable volume.

Another 22 percent of the accidents resulted in death to all of the occupants of the aircraft. A closer look at these 135 "all-killed" crashes reveals that 112 (82.9 percent) were non-survivable based on impact velocity estimates and orientations as well as damage to the occupiable space. Only 3 (2.22 percent) were determined to be definitely survivable while another 20 (14.9 percent) may have been survivable. For the latter, not enough data could be gleaned from the report summaries to reach a definite conclusion. Thus, only 2 percent of the "all fatal" crashes are definitely of interest while another 15 percent could be if more were known of the circumstances.

Table IV is a summary of general crash environments for each of the aircraft types included in the survey period. The categories listed are a water/aircraft carrier environment or a land environment. The water/aircraft carrier environment includes all accidents which occurred on takeoff or landing on a carrier and accidents in which the aircraft came to rest in the water. All other accidents were considered to have a land environment even though the aircraft may have hit buildings, trees, or other land obstacles. For mid-air collisions, the final resting place was used to determine the general environment.

FIRSTHAND DATA

The firsthand data were accumulated in interviews with Naval personnel and by inspection of crash-damaged aircraft at Naval facilities. Safety officers, survivors, witnesses, and investigators concerned with Naval aviation were interviewed. These personnel were asked questions concerning impact variables of particular accidents in their experience as well as questions concerning injuries and causes, aircraft damage, fire, and escape problems.

Table V summarizes the trips and visits made to Naval and Army facilities in gathering the firsthand data in this program. The information obtained at these facilities is summarized below.

TABLE V. SUMMARY OF VISITS TO NAVAL AND ARMY FACILITIES

Facility	Purpose of Visit(s)	Number of Trips
Office of Naval Research (ONR), Arlington, Virginia 22217	Clarify scope of contract and identify potential areas of investigation	1
Naval Air Systems Command (NAVAIR), Arlington, Virginia	Obtain background information on Naval aviation crash problems	1
Naval Safety Center (NSC), Norfolk, Virginia 23511	Obtain documented crash data on Naval aircraft	2
Naval Air Facility (NAF), El Centro, California	Obtain crash environment data on land based jet aircraft	1
Naval Air Rework Facility (NARF), North Island, California	Examine crash-damaged Naval/Marine aircraft	1
Naval Air Station (NAS), Imperial Beach, California	Interview survivors and witnesses of Naval aircraft accidents	1
U. S. Army Board for Aviation Accident Research (USABAAR) Fort Rucker, Alabama	Compare Army accident data requirements and handling with Navy's	1

Interviews conducted at the Naval Air Station in Imperial Beach, California with survivors, witnesses, and investigators of Naval aircraft accidents covered 21 different helicopter crashes and 8 propeller-driven aircraft accidents. Of the 21 helicopter accidents, 15 of the aircraft came to rest in water, 2 in rice paddies, and the other 4 on the ground. Four of the accidents concerned UH-1 models. In 2 of these cases survivors stated that the transmissions came loose from their mounts but did not enter the cabin area. Two persons were killed in these accidents. In one accident the aircraft rolled over an occupant who had jumped out while the aircraft was still moving. The other fatality was due to drowning. In 2 cases the aircraft caught fire, and in another case some of the occupants were burned by leaking JP fuel, although there was no fire.

Four more of the accidents involved H-2 helicopter water impacts. The only major injury was a broken arm sustained by a crewman restrained only by a gunner's belt. He was thrown into the cabin structure upon impact (accident 33 in Table II).

Nine of the interviews covered H-3 accidents and only 2 of these occurred on land. In 3 cases the pilot or copilot, or both, were ejected through the windshield while still restrained in their seats. In one case the pilot stated that, although his seat came loose from the aircraft, he was not thrown out because the nose compartment rolled up on impact and trapped his leg (accident 34 in Table II). One pilot who survived a water impact stated that the occupants encountered a multitude of problems getting out of their aircraft because it rolled/inverted and was filling with water. There was difficulty opening one of the escape hatches and the other hatches were hard to find due to darkness. The survivor suggests that possibly some modification could be made to automatically eject the escape hatches on impact with water. He also suggested that water activated lights be placed around the escape hatches. Another possibility is a system such as the H-46 uses wherein sensors located in the stub wings turn on the cabin lights if the impact force is greater than 3G. Another problem was the canvas-type sound proofing used in the cabin area coming loose upon impact and entangling the survivors. The most difficult problem faced by one survivor interviewed was that his life preserver was bulky and buoyant even when not inflated, making it extremely difficult to dive through the escape hatch of his inverted aircraft.

General comments concerned lack of adequate seat retention and the tendency of helicopters to roll about the longitudinal axis when the rotor stops turning after water impact.

Discussions held with personnel at the Naval Air Systems Command (NAVAIR) in Arlington, Virginia were general in nature and were directed at obtaining background information on Naval aviation crash problems. It is worth noting that the NAVAIR people expressed the opinion that the improvement of structural crashworthiness is a much less feasible goal for the high performance jet aircraft than for helicopters and non-jet fixed-wing aircraft.

Conversations with Safety Center personnel in Norfolk, Virginia corroborated the opinion of the NAVAIR personnel. At the Naval Safety Center, discussions were also held with several helicopter accident investigators. These investigators expressed the opinion that helicopter crashworthiness could and should be improved in the following areas:

1. Fuel, oil, and hydraulic systems to minimize post-crash fire.

2. Seat retention.

3. Retention of heavy power plant components.

4. Door retention.

Discussions with the safety officer and fighter pilots at the Naval Air Facility in El Centro, California centered on high performance jet aircraft. The opinion was expressed that the landing gear on the A-4, for example, is too narrow for adequate stability during touchdown. This gives this aircraft a tendency to roll if the landing is not smooth. However, to widen the gear becomes a tradeoff since it would necessitate beefing up the wing, thereby increasing the weight and decreasing the design capabilities of the aircraft. One interesting improvement suggested would be the addition of some sort of heat shield between the cockpit and the fuel tanks which are located directly behind the occupants in some jet aircraft. This would give the occupants more time to escape in case of fire.

The Naval Air Rework Facility at North Island, California was visited for a firsthand look at crash damaged Naval and Marine aircraft. Various kinds of crash damage were noted and photographs were obtained of some of the aircraft for use in this report.

The U. S. Army Board for Aviation Accident Research (USABAAR) was also visited for a comparison of the type of data and methods by which aircraft accident data are recorded, stored, and retrieved.

ANALYSIS AND DISCUSSION

The generated data base was used for a variety of analyses aimed at determining fatality causation, injury patterns, impact variables, crash environments, and survival problems in Naval/Marine aircraft. The analyses are described and discussed in this section.

Problems concerning Naval helicopters are covered more thoroughly than jet and non-jet fixed-wing aircraft primarily because of the relative amounts of data available. One reason for this is that there is often time to eject or bail out in a fixed-wing aircraft emergency. In such cases, crashworthiness of the aircraft is no longer relevant to crash survival and accidents of this type were not included in the survey. At present, however, there is no sure way of safely escaping from a disabled helicopter in the air, although methods of accomplishing it have been proposed and tested successfully.[11,12] Even when airborne escape systems become operational, crashworthiness of Naval and Marine helicopters will still be of primary importance because the escape capsule must also be crashworthy.

Table III shows that within the survey period, helicopter accidents involved the most people, with 1,039 total occupants compared to 445 in jets and 597 in non-jet fixed-wing aircraft. Helicopters also had the greatest number of accidents with injuries, with a total of 91 as compared to 17 for jets and 25 for non-jet fixed-wing aircraft. Many more occupants were injured in helicopter accidents (273) than in jets (23) or propeller driven aircraft (68). More helicopter occupants (66) were killed in survivable accidents than occupants in jet (4) and non-jet fixed-wing aircraft (36). These statistics clearly indicate that the most fertile field for saving lives and reducing injuries lies in helicopter crashworthiness improvement.

FATALITY CAUSES

The primary objective of crashworthiness research is to determine how to reduce fatalities and injuries in crash situations. In order to meet this objective, the first task is to find the causes of fatalities in the various types of aircraft crashes for land and sea crash environments. Some preliminary comments are in order.

On the basis of percentage of occupants killed, jet aircraft are the most dangerous of the Naval aircraft since 28.8 percent of the occupants in the major jet accidents surveyed received fatal injuries. The aircraft with the next highest percentage were non-jet fixed-wing aircraft in which 25.3 percent of the total occupants of accidents surveyed were killed. Helicopters had the least percentage of occupants killed, only 14.1 percent.

Because of the small number of occupants, jets have the lowest fatality rate; only 0.407 occupants were killed per major accident. The next lowest were light non-jet fixed-wing aircraft with 0.488 persons killed per major accident. There were 0.802 persons killed per major helicopter accident. The most dangerous as far as fatalities per accident were the heavy (over 12,500 pounds) non-jet fixed-wing aircraft in which 1.83 persons died per major accident.

A total of 147 occupants were killed in the helicopter accidents surveyed, while 130 were killed in heavy non-jet fixed-wing aircraft,* 128 were killed in jet aircraft, and 21 were killed in light non-jet fixed-wing aircraft. The causes of of these fatalities (where they could be determined) are summarized in the following paragraphs.

*The patrol aircraft, which have both propellers and jet engines, were included with the non-jets since their jet engines are not normally used in patrolling.

Fatality Causes in Navy Helicopters

The variations in fatality causes for Navy helicopter land and water impacts are shown in Figure 1. This figure also includes the total number of fatalities occurring for each helicopter type in water and land impacts so that the reader may judge the significance of the resulting graph. As expected, for water impacts, drowning is the major cause. A total of 23 of the 42 fatalities in water impacts were caused by drowning. Another 16 were listed as lost at sea. Most of these fatalities were probably due to drowning but, unless the body was recovered and an autopsy revealed that drowning was the cause of death, the medical report listed only lost at sea. Only 2 of the 42 deaths in helicopter water impacts were directly attributed to impact while 1 death was due to fire.

On land, however, impact and fire were the major fatality causes in the survey period. Of the 104 land fatalities in Navy helicopters, the medical reports listed impact as the major cause of 72 fatalities, fire as the major cause of 29 fatalities, and rotor blade strikes as the cause of 3 fatalities.

Figure 2 shows the distribution of fatality causes in "all-killed" crashes, survivable crashes, and total crashes for Navy helicopters in the survey period. There were a total of 80 killed in "all-killed" crashes and 66 killed in survivable accidents. In survivable accidents, 36 of the total 42 water impact fatalities were recorded while only 30 of the 104 fatalities in land impacts occurred in this category. Almost three-fourths of the fatalities in "all-killed" crashes were caused by impact. In fact, 4 of every 5 impact fatalities were in non-survivable accidents.

It is interesting to note that no pilots were killed in the 18 H-3 helicopter accidents included in the survey; the overall death rate for this type helicopter was the lowest of

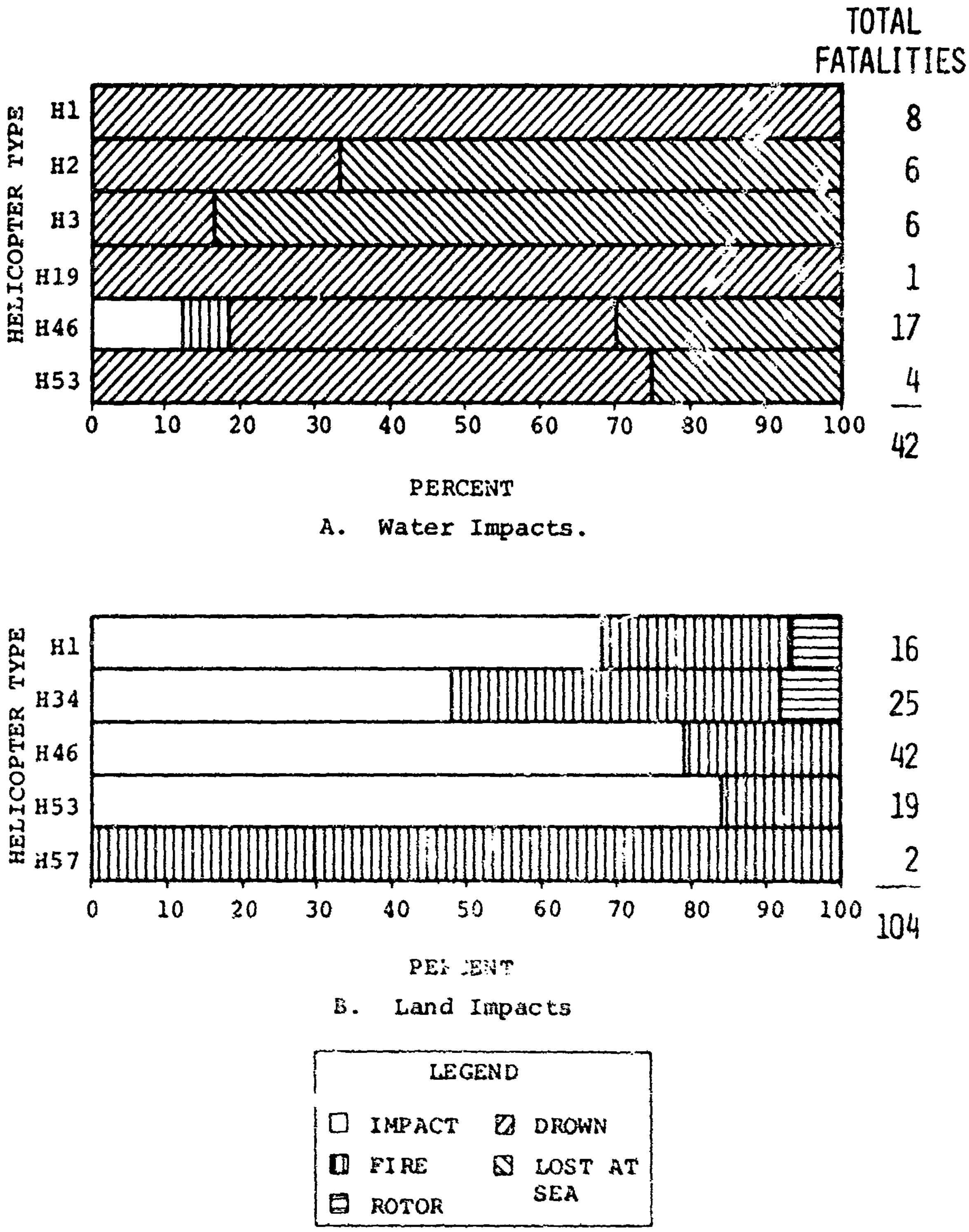


Figure 1. Percent Fatalities By Cause in Naval Helicopter Accidents By Helicopter Type (January 1969 through May 1971).

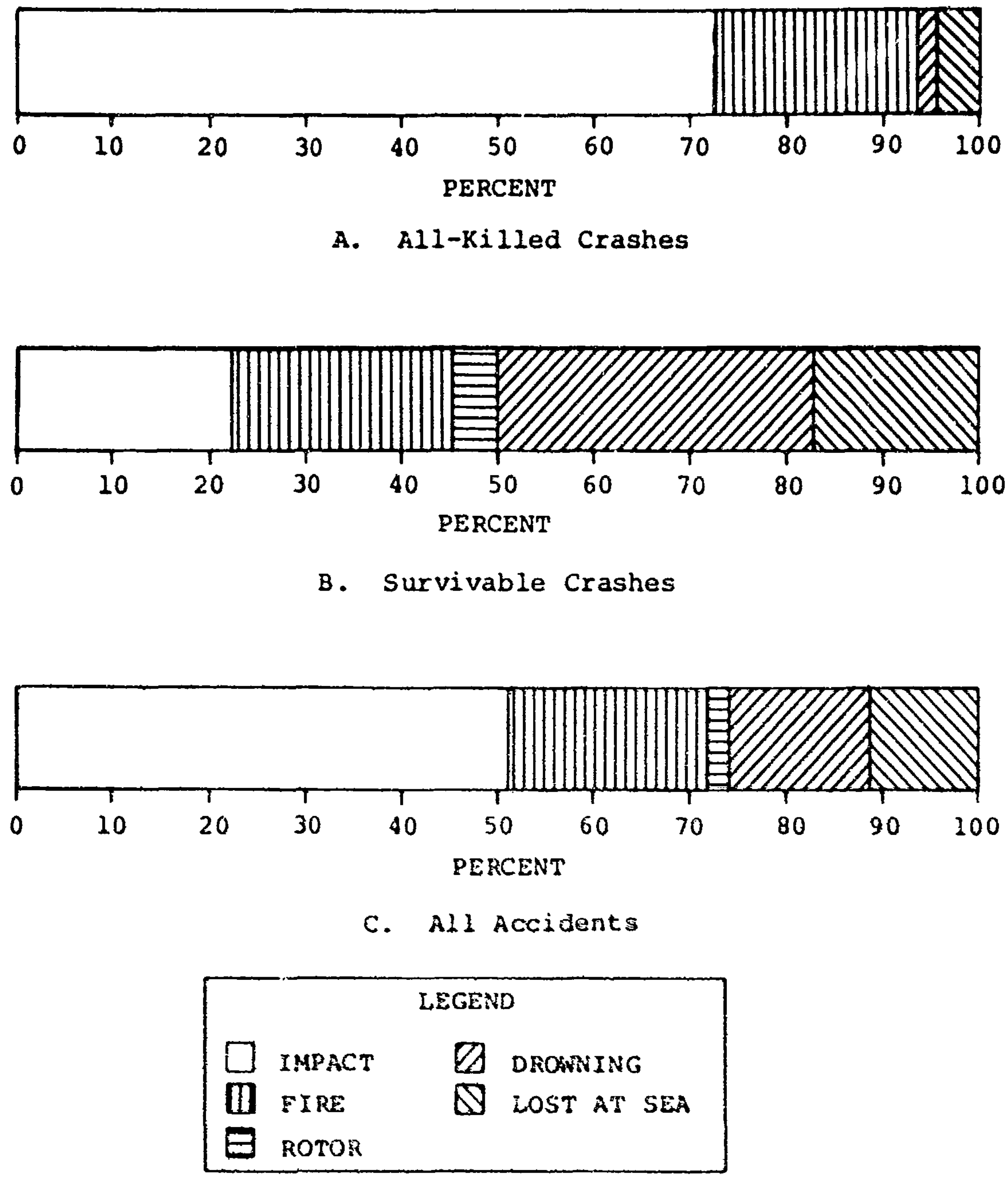


Figure 2. Percent Fatalities By Cause For Navy Helicopter Accidents (January 1969 through May 1971)

any of the Naval helicopters in the survey. The highest fatality rate occurred in H-34 helicopters with nearly 30 percent of all occupants killed in the 24 accidents surveyed. The pilot fatality rate was the lowest of any of the occupants in H-34's. This may be because the pilot sits much higher than passengers and crewmen in this aircraft and has more crushable material between him and the impact surface to absorb the kinetic energy of the crash. In contrast, passengers in the newer cargo/troop transport helicopters (H-46 and H-53) were among the safest of passengers, since less than 15 percent received major (or fatal) injuries in each type compared to over 50 percent passenger fatalities in H-34 accidents.

Impact injuries were the cause for less than one-fourth of the fatalities which occurred in survivable crashes. Drowning was the major cause in survivable Navy helicopter accidents with half either drowned or lost at sea. Thermal injuries also caused nearly one-fourth of the survivable helicopter accident fatalities. It should be noted, however, that impact injuries were probably a contributing factor in most of the fatalities since a stunned or injured occupant would be less able to escape from a burning or sinking helicopter.

Thermal injuries accounted for nearly the same percentage of fatalities in both survivable and "all-killed" accidents. It is expected that this percentage could be greatly reduced by the implementation of crashworthy fuel systems. Improved helmets and padding could probably reduce the number of Naval airmen drowned and lost at sea by keeping them physically able to accomplish a rapid escape. The same holds true for the fire-caused fatalities.

Deaths in Fixed-Wing Aircraft

In jet aircraft, 106 of the total 128 killed died in accidents which were considered non-survivable based on the impact velocities. This high proportion of nonsurvivable accidents is a function of the high impact speeds usually experienced in high performance jet accidents. Table VI summarizes the fatality causes for Naval jets.

TABLE VI. FATALITY CAUSES IN NAVAL JETS FOR ACCIDENTS IN WHICH EJECTIONS DID NOT OCCUR (JANUARY 1969 TO MAY 1971)

Cause	Number	Percent
Impact	74	57.7
Drown	3	2.4
Fire	2	1.6
Lost at Sea	49	38.3
TOTAL	128	100.0

The bodies of nearly 40 percent of the jet aircraft accident fatalities were not recovered because the accidents occurred at sea. However, the bodies of pilots recovered from similar water accidents indicated that death was usually caused by multiple extreme impact injuries rather than drowning. It is estimated that nearly 90 percent of the jet fatalities are due to high impact injuries for which there is no realistic prevention by use of energy-absorbing structure. The present emphasis on ejection seats is probably the most feasible method of minimizing jet aircraft accident fatalities.

For non-jet fixed-wing aircraft, impact was again the leading fatality cause for both light (under 12,500 pounds) and heavy (over 12,500 pounds) aircraft. The causes are summarized in Table VII.

Over 30 percent of the non-jet fixed-wing aircraft fatalities were lost at sea. Nearly 10 percent died of burns and only a small percentage are known to have drowned. Of the ones

TABLE VII. FATALITY CAUSES IN NON-JET FIXED-WING NAVAL AIRCRAFT (JANUARY 1969 TO MAY 1971 APPROXIMATELY)						
	Under 12,500 Pounds		Over 12,500 Pounds		All	
Cause	Number	Percent	Number	Percent	Number	Percent
Impact	17	85.0	70	53.4	87	57.7
Fire	2	10.0	12	9.2	14	9.3
Drown	0	0	3	2.3	3	2.0
Lost at sea	1	5.0	45	34.3	46	30.4
Other*	0	0	1	.8	1	.6

*One crewman choked on food which lodged in his throat in the accident.

lost at sea, most were probably killed by impact forces or severely debilitated, which precluded their escape and caused death by drowning.

Comparisons of Death Causes

Comparing Figure 2C with Tables VI and VII shows that, within the survey period, the percentages of fatalities for all Naval aircraft due to impact forces is fairly similar (50.5 percent in helicopters versus 57.7 percent in both jet and non-jet fixed-wing aircraft). The highest incidence of fire-caused fatalities is in helicopters (21 percent) while the non-jets were about half that (9.3 percent). Fire-caused fatalities in jets amounted to less than 2 percent of the total. The percentage of occupants lost at sea was nearly three times larger in non-jet fixed-wing and nearly 4 times larger in jets than in helicopters.

Effect of Impact Surface on Crash Survivability

The impact surface had a definite effect upon the survivability of the major accidents in the survey. Table VIII shows the fatality rate per major accident for various impact surfaces and four categories of Naval aircraft. The fatality rates for impacts with flight decks and runways were low for all types of aircraft. This can probably be attributed to much quicker emergency rescue and medical treatment being available in such cases. Impacts in trees or dense forests had the highest fatality rates for the helicopters surveyed. This was surprising because of contradictory findings in a USABAAR publication concerning emergency landing and ditching techniques in helicopters.[13] This publication states that Army accident experience proves conclusively that trees can be a helicopter pilot's best friend in an emergency situation. The difference between accidental or uncontrolled impact with trees and intentionally settling in trees and using them as an energy absorber is probably the explanation.

TABLE VIII. FATALITY RATES PER MAJOR ACCIDENT FOR DIFFERENT IMPACT SURFACES AND NAVAL AIRCRAFT (JANUARY 1969 TO MAY 1971)

Impact Surface	Type of Aircraft			
	Attack	Fighter	Helicopter	Cargo
Water	1.18	1.55	0.70	12.33
Flight Deck	0.02	0.08	0	0
Runway	0.10	0.03	0.24	0
Ground	0.40	0.61	0.77	3.50
Trees	1.00	1.33	1.67	1.33
All	0.37	0.44	0.80	2.55

Attack, fighter, and cargo aircraft had the highest fatality rates for accidents in which the aircraft impacted water. In most cases, the water impact fatalities were lost at sea for these aircraft while water fatalities in helicopters were more often caused by drowning. The water fatality rate in helicopters was less than either the tree or ground impact rates.

The overall fatality rates are also given for each category of aircraft in Table VIII. The overall rates include not only the terrains listed in Table VIII but also such categories as snow, swamps, and unknown terrain. Swamp impacts did have a high fatality rate in helicopters with 21 killed in 16 crashes (1.31 fatalities per major accident), although it was a minor category for other types of aircraft. The swamp impacts were mostly in Vietnam rice paddies. Water and tree impact fatality rates were approximately 3 times the overall fatality rates in attack and fighter aircraft.

INJURY PATTERNS

The injuries received in aircraft accidents are a function of the impact forces, but they may also be related to positioning and tie-down of components, padding of the occupiable areas, stiffness and energy-absorbing capabilities of the aircraft structure and seats, and the adequacy of helmets and restraint systems. A study of the injury patterns can thus point to some of the problems which exist in present aircraft. A discussion follows of the injury patterns which emerged from the analysis of the accidents and various types of Naval aircraft surveyed.

Helicopter Injury Pattern

All injuries listed in the medical report summaries for occupants of the 183 Naval helicopters in the survey were used in compilation of the injury pattern except burns, drowning, and multiple extreme injuries. The results are shown in Figure 3. The percentages are based on the total number of injuries listed rather than the total number of occupants. Some occupants had more than one injury. The total number of injuries included in the figure was 363. As the figure shows, leg, head, and arm injuries were the most prevalent types. These are the types of injuries which may best be minimized by improved helmets, improved restraint systems, and better padding. The next highest injury incidences were back (spinal) injuries. Energy-absorbing seats could be used to minimize this type injury.

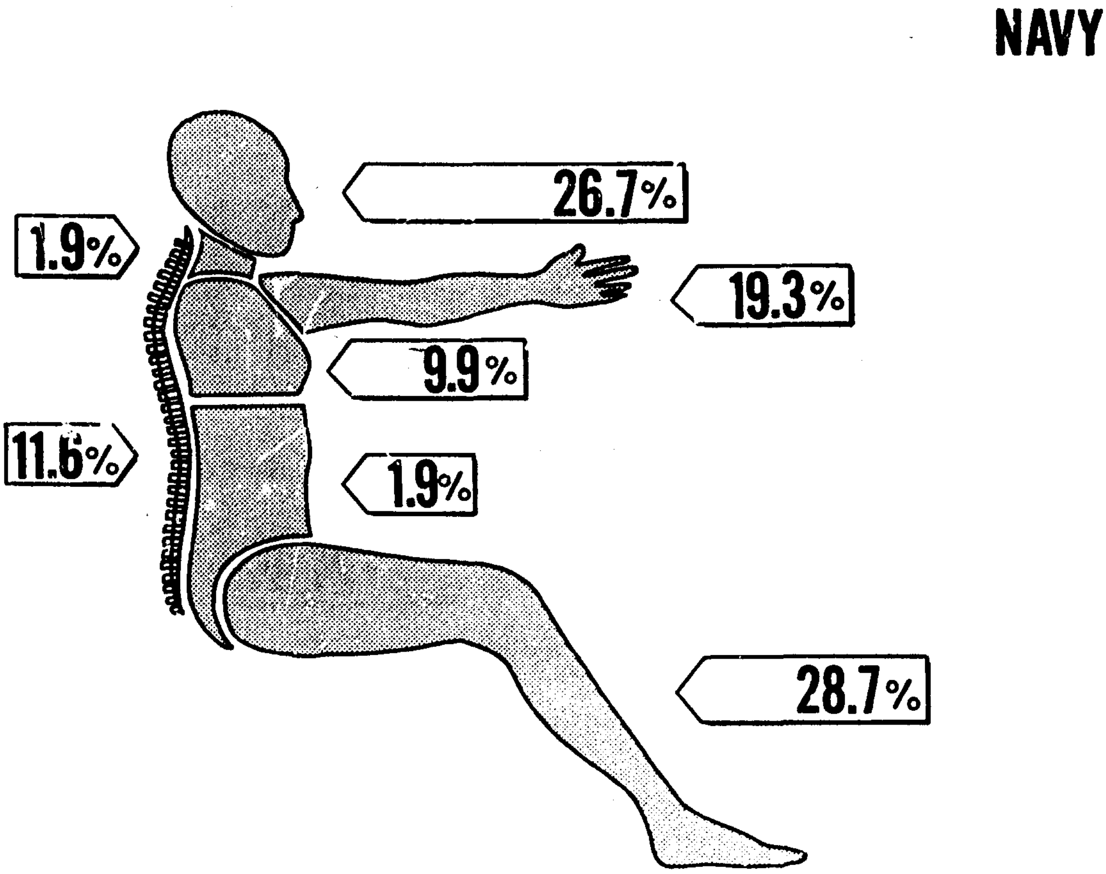


Figure 3. Injury Pattern for Naval Helicopter Occupants (January 1969 through May 1971).

Figure 4 contains the U. S. Air Force and Army injury patterns reported in Reference 8. The Army injury pattern is for helicopters only, while the Air Force pattern includes various types of aircraft. Comparison of these with the injury patterns for Naval helicopters show that leg injuries are more prevalent in the Navy injury pattern than in the Air Force and Army patterns. Back injuries are comparable in Army and Navy helicopters but are much higher in the Air Force aircraft accidents. This has been attributed to the greater overall strength of the high performance aircraft included in the Air Force data.[8] The Army and Air Force patterns also show a prevalence of head, leg, and

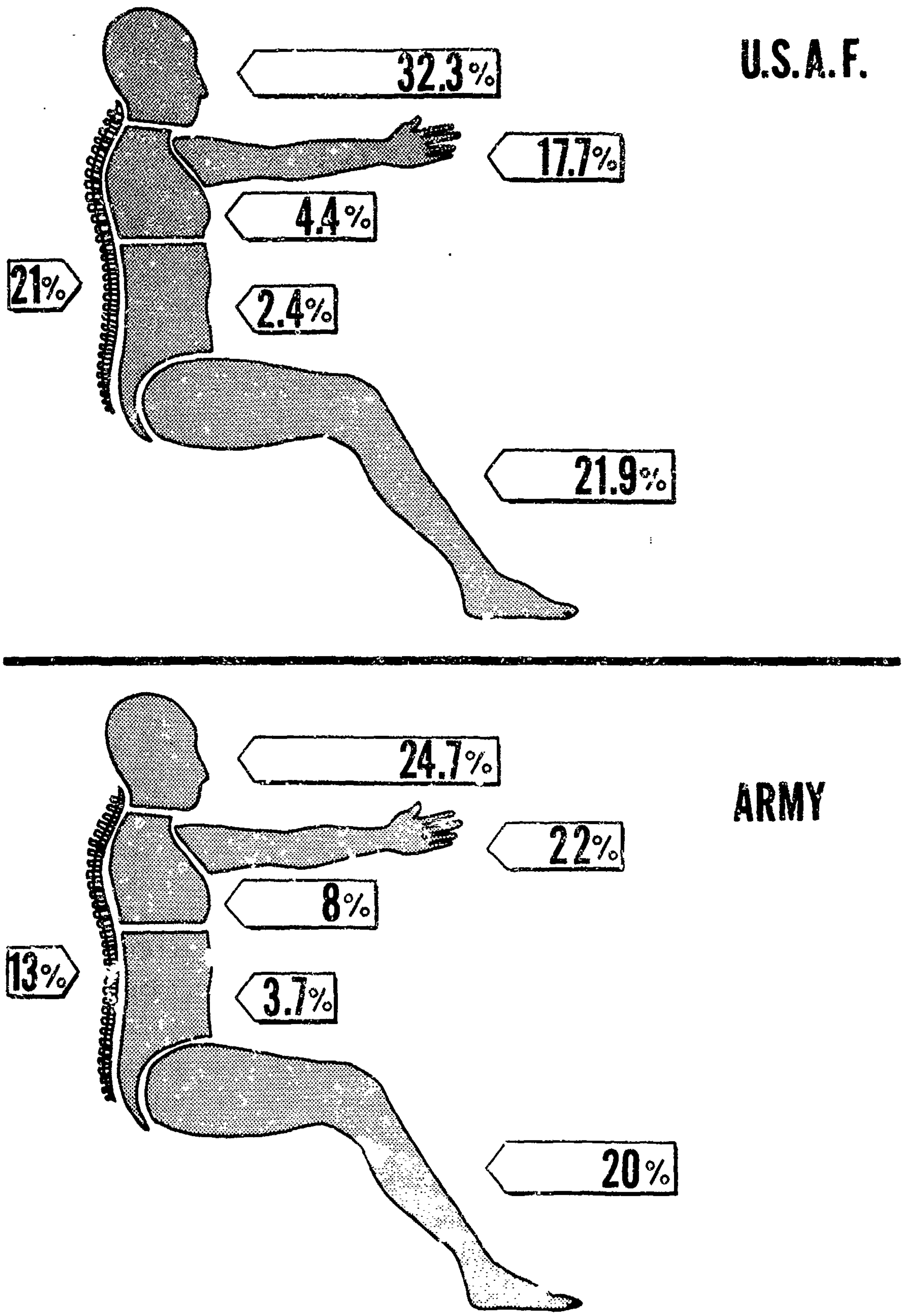


Figure 4. Air Force and Army Injury Patterns.

arm injuries as noted in the Navy helicopter injury pattern; therefore, these appear to be a universal problem.

Jet Aircraft Injury Pattern

A jet aircraft injury pattern is not provided as there were insufficient data available to make it statistically meaningful. Although there were 314 jet aircraft accidents surveyed, there were only 8 occupants with major injuries among the 445 occupants. Of the 128 killed, most were either lost at sea or received multiple extreme fatal injuries which were not listed individually on the accident reports. The injury pattern for the U. S. Air Force in Figure 4 was compiled from over 8,000 occupants and would probably be applicable to a Naval jet aircraft accident injury pattern.

Fixed-Wing Transport Aircraft Injuries

There was one severe transport aircraft accident in the survey period with enough occupants aboard to establish some significant injury trends. The accident involved an EC-121M with 31 occupants aboard (accident 17 in Table II). Only one of the occupants escaped injury while another received minor injuries, 6 had major injuries, and 23 were killed. The medical report stated that a high percentage of the injuries was caused by seat and console mounting failure on impact. The medical officer stated that many of the head injuries would have been minimized if a requirement for helmet use had existed.

The injuries received by the occupants aboard the aircraft are summarized in Table IX as percentages of occupants receiving injuries to particular body areas. Percentages are given for fatally injured occupants, occupants with major injuries, and all occupants. Because many of the occupants were not wearing helmets, it is not surprising that a high percentage received major head injuries. The typical trends toward head, leg, and arm injuries in all the injury patterns discussed so far were again evident in the transport accident.

TABLE IX. SUMMARY OF OCCUPANT INJURIES IN A SEVERE TRANSPORT AIRCRAFT ACCIDENT (EC-121M)

Body Part	Percentage of Occupants Receiving Injuries to Body Parts		
	Fatally Injured Occupants	Occupants With Major Injuries	All Occupants
Skull	78.5	83.3	74.2
Legs	65.3	50.0	58.2
Arms	43.5	33.3	39.7
Chest	21.7	0	16.1
Back	0	16.7	3.2
Abdomen	4.4	0	3.2

From a crashworthiness standpoint, the single most significant factor which emerged from the data on this accident was the fact that all 8 of the persons who survived the crash were seated in rearward facing seats.

It is also significant to note that the percentage of injuries received by the occupants with major injuries are nearly identical to those reported by Dynamic Science[8] in a study of 800 survivors with injuries in light civilian fixed-wing aircraft. The reasons cited for the trends noted in the Dynamic Science study were lack of helmets and shoulder restraint in most light civilian aircraft.

INJURIES AS A FUNCTION OF OCCUPANT DUTY/LOCATION

Another revealing factor from a crashworthiness standpoint is the relative severity of injuries received by occupants in various locations in the aircraft. For example, if a significantly larger number of pilots received injuries than did copilots in a particular aircraft where they are seated side by side, this may indicate that some object in the pilots' strike zone should be relocated. Or, if injuries are more severe in the cabin area than in the cockpit area, it could mean that the cabin area needs improved restraint systems since, more often than not, forward occupants, i.e., those in the cockpit area, are subjected to higher G loads. The following paragraphs are concerned with the degree of injuries received by the various occupants in Naval aircraft.

Helicopter Injuries

Figures 5 through 9 are composite injury histories by duty function of the occupant for all the helicopters included in the survey. Bar charts are shown for pilots, copilots, crewmen, crew chiefs, and passengers with a composite figure (Figure 10) for the total of all the helicopter types. All occupants of helicopter accidents which met the selection criteria are included in the figures. The degree of injury was broken up into four categories: fatal, major, minor, and none.

The portions pertaining to the H-19 and H-57 helciopters are not statistically significant since there were only two H-19 accidents and four H-57 accidents included in the survey. They are included in the figures, however, for completeness.

Figure 10 indicates that the occupants involved in H-53 accidents were more likely to be injured than occupants of any of the other helicopters included in the survey. One reason being that this aircraft was involved in some of the more serious survivable accidents. In fact, several of the survivable H-53 accidents were in an impact velocity range previously considered unsurvivable according to the U. S. Army Crash Survival Design Guide.

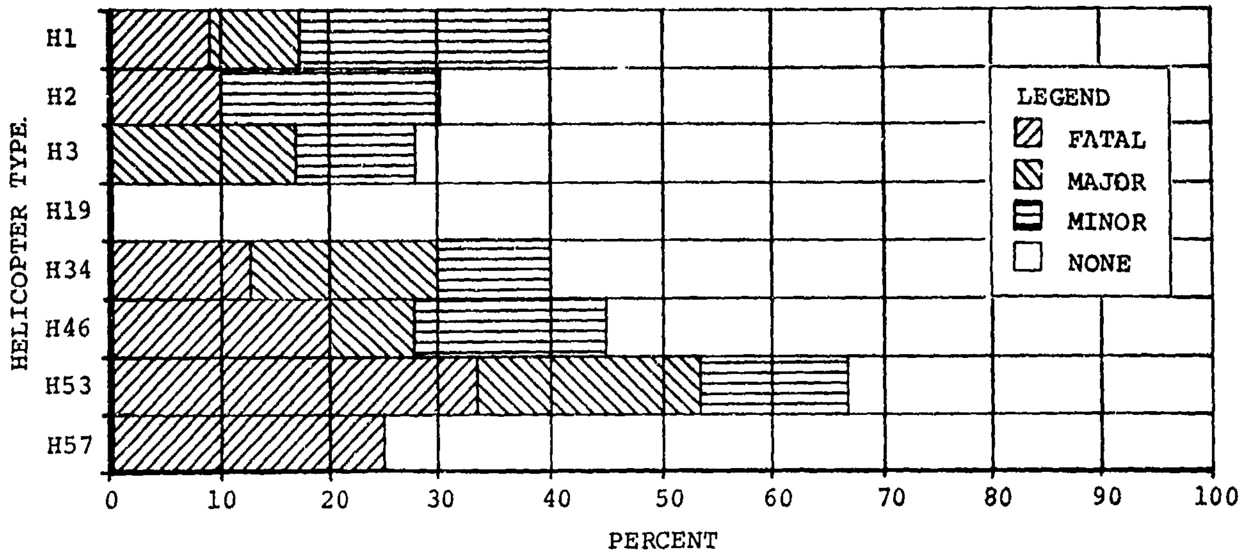


Figure 5. Pilot Injuries in Naval Helicopters
(January 1969 through May 1971).

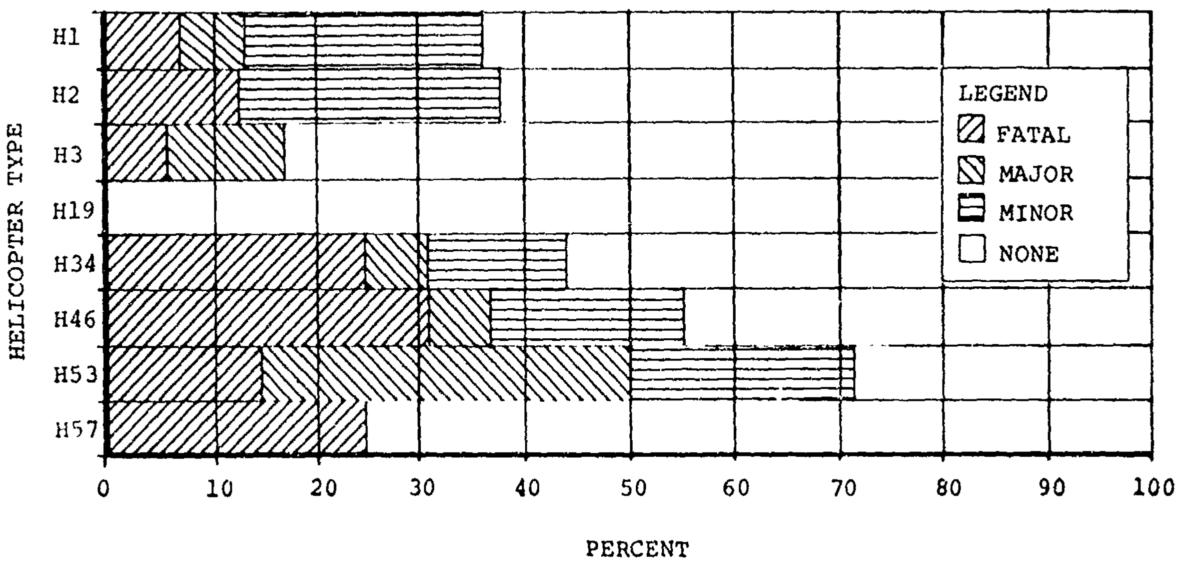


Figure 6. Copilot Injuries in Naval Helicopters
(January 1969 through May 1971).

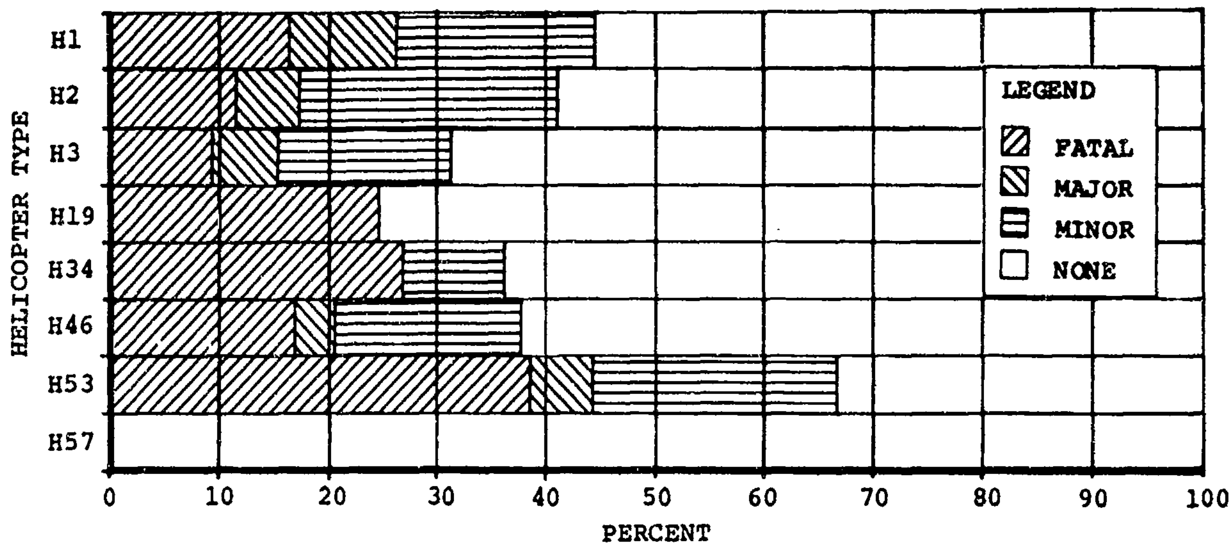


Figure 7. Crewman Injuries in Naval Helicopters (January 1969 through May 1971).

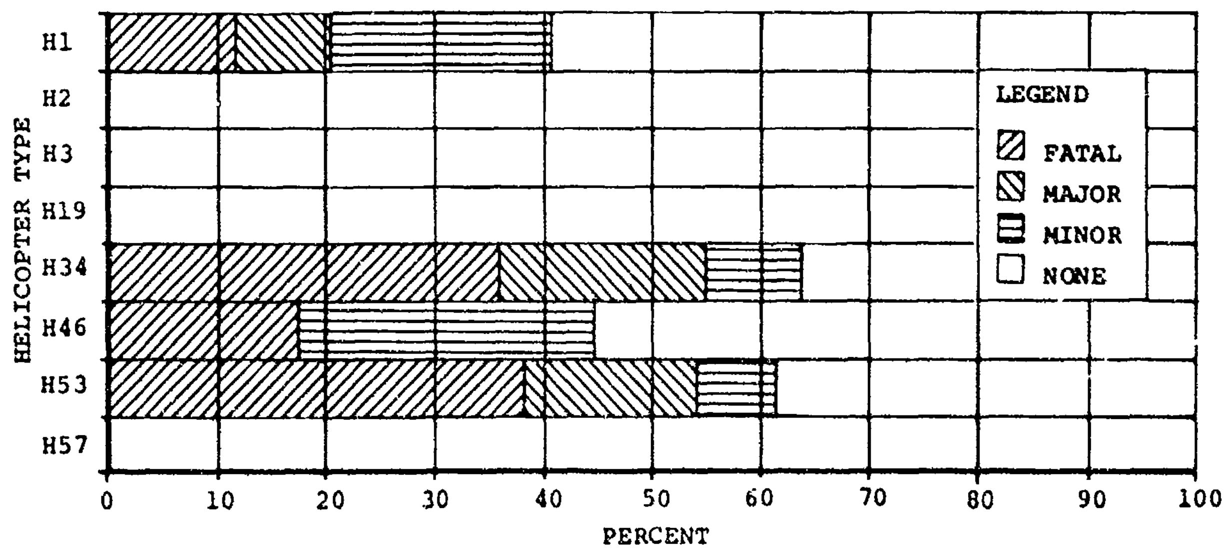


Figure 8. Crew Chief Injuries in Naval Helicopters (January 1969 through May 1971).

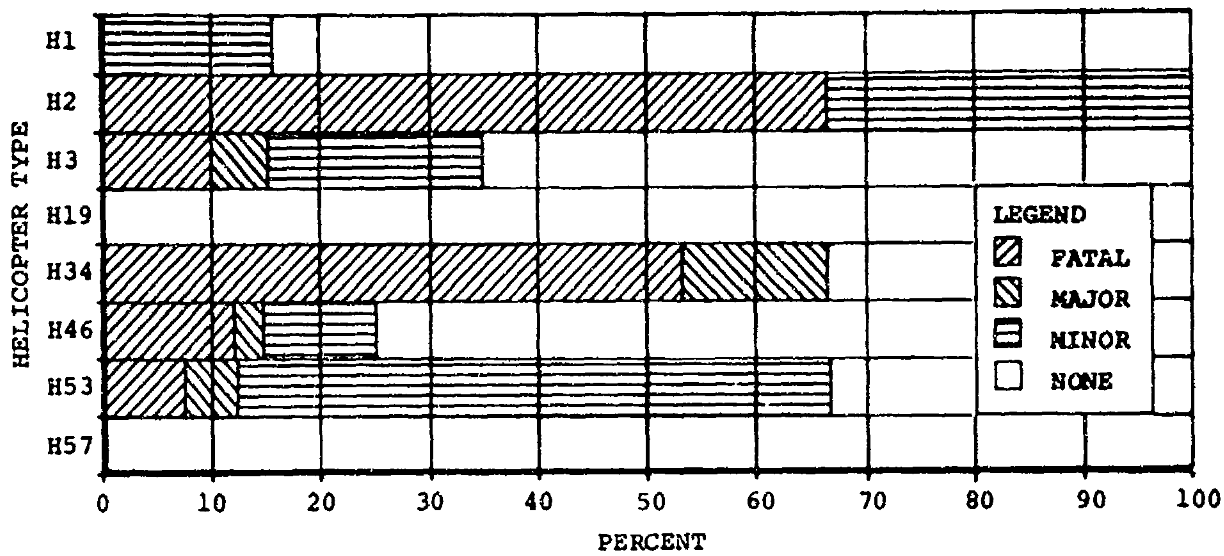


Figure 9. Passenger Injuries in Naval Helicopters
(January 1969 through May 1971).

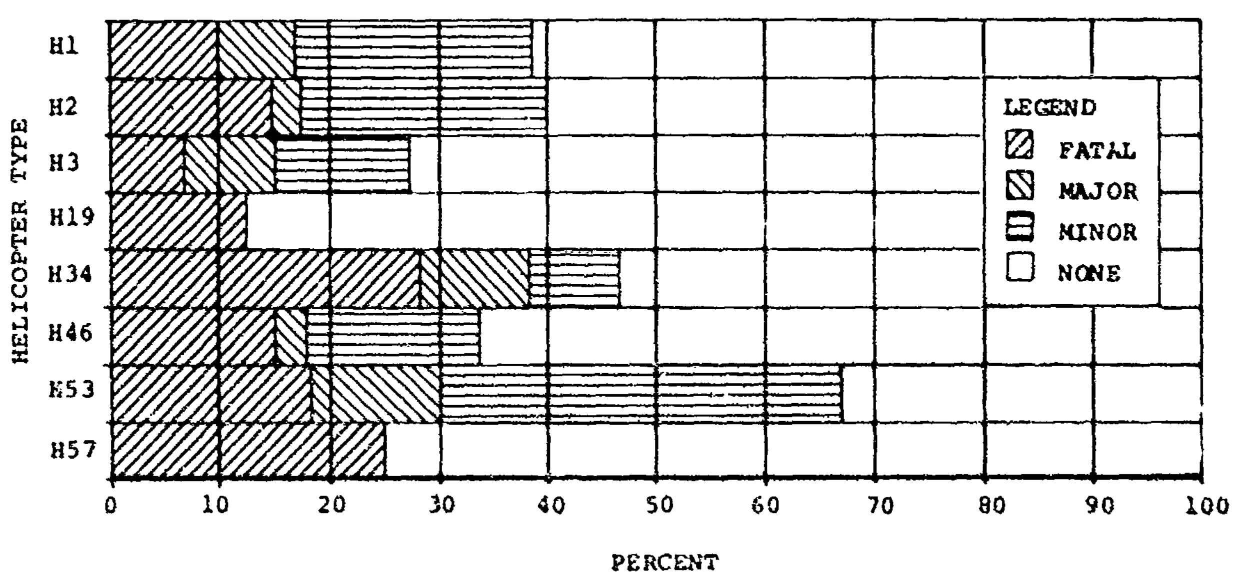


Figure 10. Total Occupant Injuries in Naval Helicopters
(January 1969 through May 1971).

Fixed-Wing Aircraft Injuries

The data from a large transport-type aircraft accident (accident 17 in Table II) were used to determine injury as a function of location for land impacts of large aircraft. Table X summarizes the data for this accident. While other accidents of this type may vary greatly as far as injury percentages for the various locations according to the impact speeds and attitudes of the aircraft involved, it is expected that similar trends would be evident. That is, if any occupants escape injury or receive only minor injuries, they are likely to be in aft facing seats in central or rear portions of the aircraft.

TABLE X. SEVERITY OF INJURY BY OCCUPANT LOCATION FOR EC-121M ACCIDENT

Locations		Occupants Receiving Injury Classification							
		Fatal		Major		Minor		None	
		No.	Pct.	No.	Pct.	No.	Pct.	No.	Pct.
Compartment	Cockpit	4	100.0	0	0	0	0	0	0
	Passenger	19	70.5	6	22.2	1	3.7	1	3.7
Longitudinal Location	Forward	14	100.0	0	0	0	0	0	0
	Center	3	37.5	5	62.5	0	0	0	0
	Aft	5	62.5	1	12.5	1	12.5	1	12.5
Lateral Location	Center	1	100.0	0	0	0	0	0	0
	Left	15	78.9	2	10.5	1	5.3	1	5.3
	Right	7	63.6	4	36.4	0	0	0	0
Direction Facing	Forward	9	100.0	0	0	0	0	0	0
	Aft	12	60.0	6	20.0	1	5.0	1	5.0
	Sideward	2	100.0	0	0	0	0	0	0

Note: Percentages are of total for each location division.

For light fixed-wing aircraft and high performance jets, there are usually not many occupants in the aircraft and they are usually located close to each other, so location may not be significant. Figure 11, however, shows the advantage of being in the rear seat in a tandem seating arrangement. The aircraft, a T-28B, stalled on a landing approach. The instructor pilot in the front seat was killed but the student in the rear seat received only minor injuries (accident 59 in Table II). The survivor of this accident was interviewed while gathering firsthand data for this program. His injury resulted from his foot getting caught under the rudder pedal.

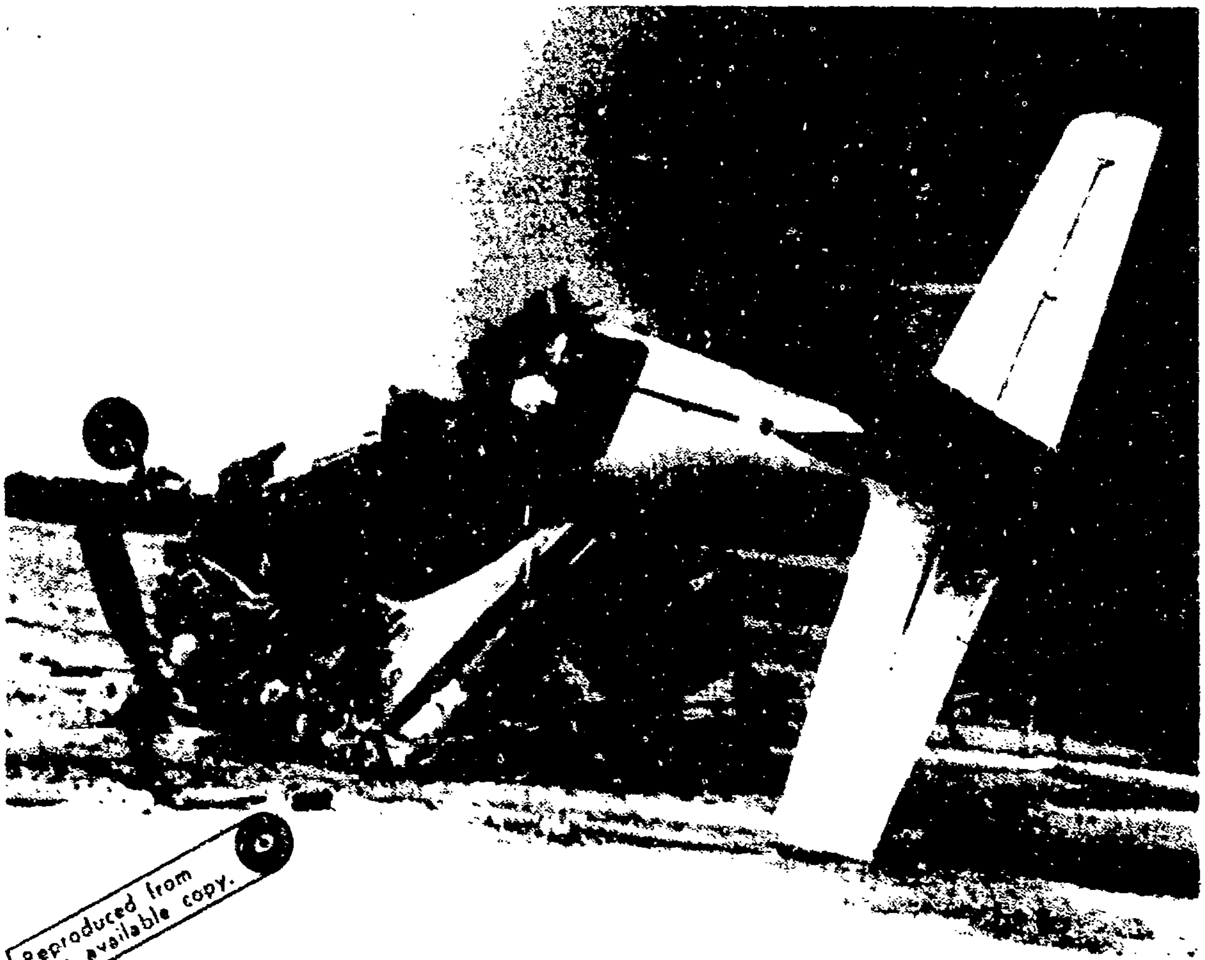


Figure 11. T-28 After a Wrapped-up Approach

Accidents 2 and 3 of Table II both concern A-3 jet aircraft. In accident 2, the only fatality was in an aft facing seat behind the cockpit (the medical report summary states that he was not wearing his helmet properly, however, which is an added consideration). In accident 3, the only survivor was in the aft facing seat behind the pilots. Thus, it is difficult to determine whether or not location is a decisive factor in the degree of injuries in high performance jet aircraft accidents.

IMPACT VELOCITY ESTIMATES

Impact velocity and velocity change during the major impact are important criteria with regard to the seriousness of an aircraft accident since both are measures of the crash energy. These factors, along with structural deformation and stopping distances, may be used to calculate decelerative loadings which the aircraft was subject to in the crash. Unfortunately, none of these factors are directly available from the present accident reports. This type of information is sometimes included in narrative form only, but it is seldom complete enough to allow accurate determination of the G loadings. The type of information necessary is exemplified in Figures 12 and 13, portions of the new U. S. Army Accident Report Form 2397 series. Some of the instructions relevant to report preparation are shown in Figure 13.

In order to allow comparison with existing information relative to impact loadings, the impact velocities were estimated for survivable accidents from narrative information concerning flight phases, maneuvers just completed, stall speeds, cruise speeds, speeds and altitudes when the emergency occurred, etc. It was not possible to determine the velocity change in the major impacts because of lack of information concerning gouge and skid patterns.

Helicopter Impact Velocities

Figure 14 shows a curve which relates cumulative frequency to estimated longitudinal impact velocity for survivable impacts

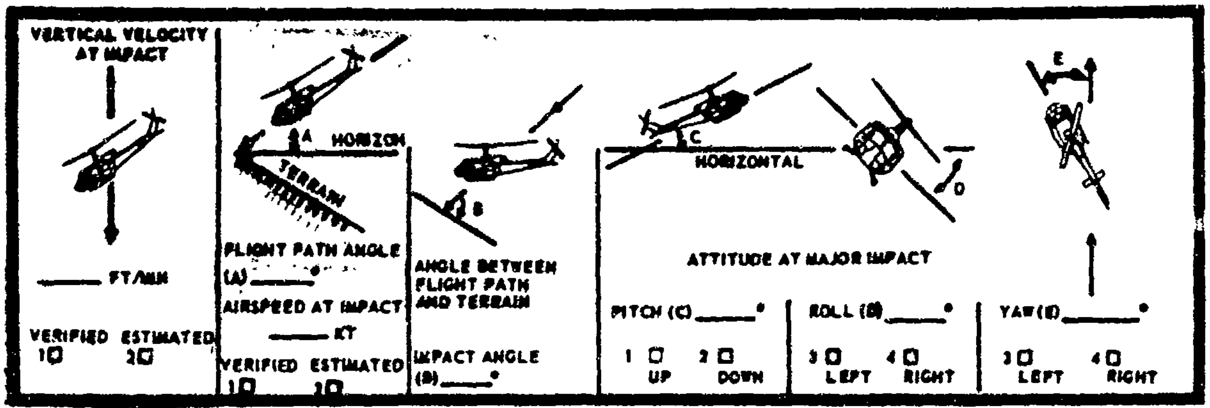
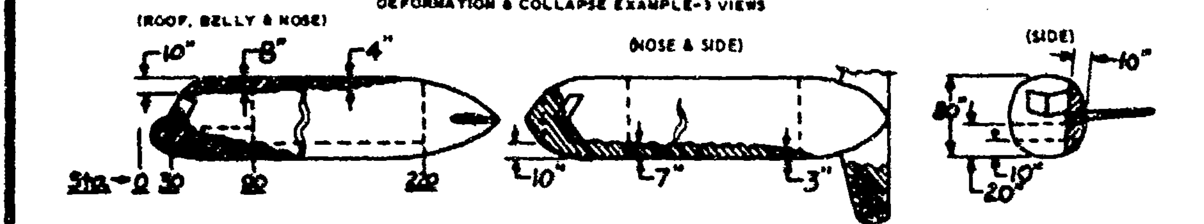


Figure 12. Velocity and Attitude Data Requested by U. S. Army Accident Report.

2. FUSELAGE INWARD COLLAPSE OR DEFORMATION

DEFORMATION & COLLAPSE EXAMPLE-3 VIEWS



FUSELAGE AREA	INWARD DEFORMATION (In inches)	STATION NO. FROM	STATION NO. TO	FUSELAGE AREA	INWARD DEFORMATION (In inches)	STATION NO. FROM	STATION NO. TO	FUSELAGE AREA	INWARD DEFORMATION (In inches)	STATION NO. FROM	STATION NO. TO
a. ROOF				c. LEFT SIDE				e. BELLY			
								f. NOSE			
b. FLOOR				d. RIGHT SIDE							
								g. REAR			

Block 2. The fuselage is divided into areas as indicated in the first columns by letters "A" through "G".

a. Record the amount of deformation in an inward direction (i.e., toward the occupiable volume) in inches in the second column for each fuselage area.

b. Indicate the distance along the fuselage over which the deformation occurs by placing the appropriate station number in the columns marked "From" and "To". If deformation occurs in more than one area along the fuselage or if the deformation gradually changes along the fuselage length, indicate the condition by specifying successive station numbers. For example, deformation occurred along the left side of the aircraft from station number 30 to 230, such that there is 9" of deformation at station number 35 which gradually decreases to 3" at station number 210. The situation could be recorded by indicating 9" of deformation from station number 35 to station number 90, 6" of deformation from station number 90 to station number 140, and 4" of deformation from station number 140 to station number 230. Note in the example that only pertinent deformation is shown. For example, nose deformation aft of station 35 is not shown even though some did occur below the cockpit floor from station 35 to station 90. The reason for this deletion is the fact that the belly is shown to be crushed upward beyond this point and the nose deformation is not applicable. Also note that a compression buckle is shown at station 130. This buckle which is approximately six inches long is recorded in areas "F" and "G" to show that a longitudinal length reduction occurred at this location.

Figure 13. Deformation Data Requested by U. S. Army Accident Report.

of Navy helicopters on both land and water. Also included in the figure is a curve taken from the U. S. Army Crash Survival Design Guide which relates cumulative frequencies and longitudinal velocity changes in the major impact for helicopters and light fixed-wing aircraft.

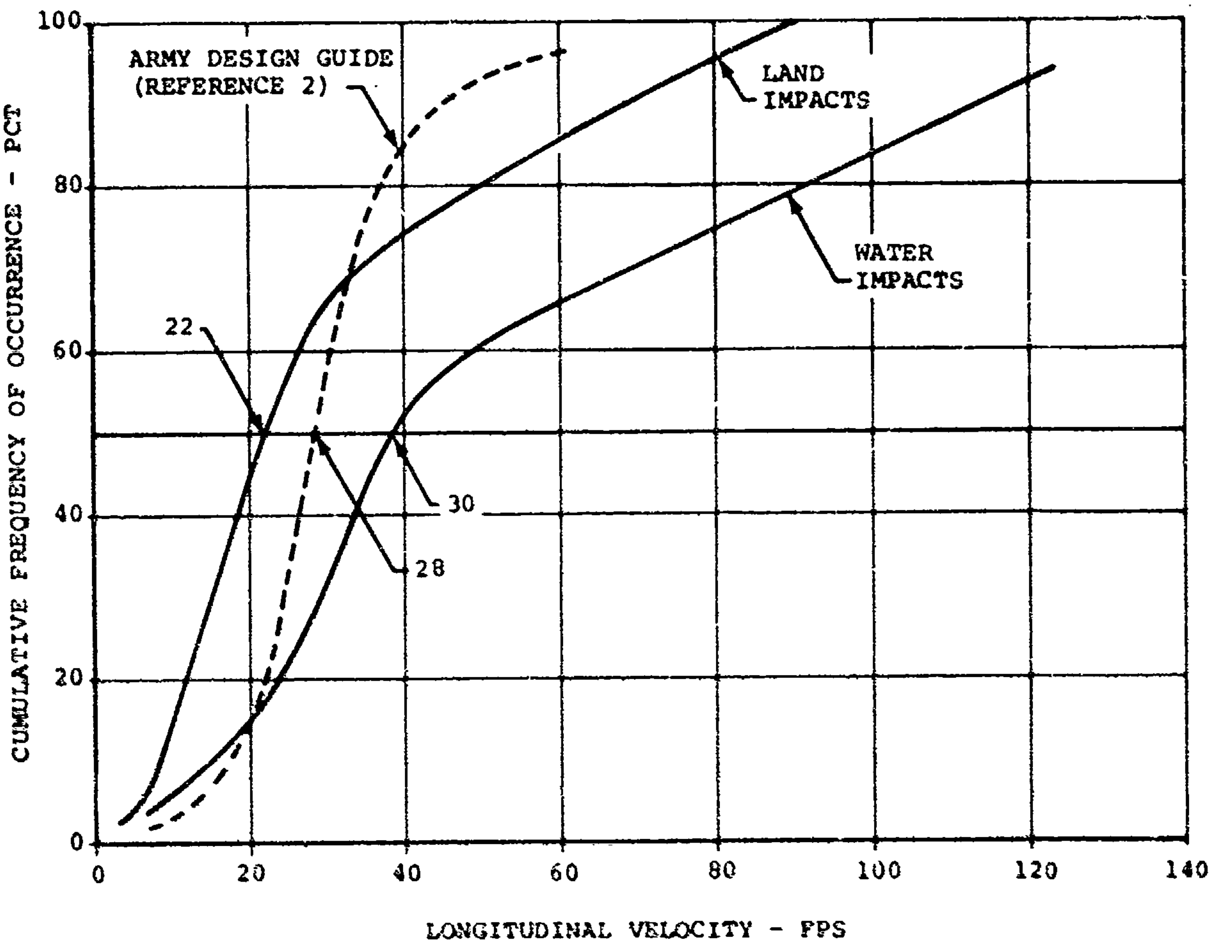


Figure 14. Cumulative Frequency Curves for Longitudinal Impact Velocities of Survivable Navy Helicopter Accidents (January 1969 through May 1971).

The figure indicates that higher longitudinal velocities are survivable in water impacts as opposed to land impacts. This is as expected since the deceleration pulse during a water crash is likely to be of lower magnitude and longer duration than that of a land crash with the same initial impact velocity.

Longitudinal impact velocity and velocity change in the major impact pulse are the same only when the velocity changes from the impact velocity to zero in one continuous pulse (assuming no rebound). This is often the case for lower impact velocities. For higher longitudinal impact velocities, however, the kinetic energy is usually dissipated in a series of skidding, gouging, bouncing, and rolling movements rather than a single continuous deceleration. For this reason, it was expected that the cumulative frequency curves for Navy helicopter land and water longitudinal impact velocities would be higher than the longitudinal velocity change curve taken from the Army Crash Survival Design Guide. Such is the case for water impacts. However, the estimated velocities for Navy land impacts are lower up to the 60-percent level than the Army's curve. One possible explanation for this is that light fixed-wing aircraft impacts are also included in the Army curve whereas the Navy curve contains only helicopter impacts. Another possible explanation is that the Army curve is a combined curve which also contains Navy and some civilian data. The Navy water impacts which it contains may have shifted the curve from where a land-only curve would lie. Other possible explanations for more injuries than expected at lower velocities are misuse, lack of, or inadequate restraint systems. The Army curves for vertical and longitudinal velocity change do not necessarily include the same accidents for both curves while the curves for Navy helicopters include both. This could account for some of the differences.

Cumulative frequency curves for vertical impact velocities in survivable land and water Navy helicopter accidents are shown in Figure 15. This figure also includes a cumulative frequency curve for vertical velocity change in the major impact pulse for survivable rotary and light fixed-wing aircraft which was taken from the Army Crash Survival Design Guide. All three curves have the same general shape and the magnitudes are reasonably close to each other. For vertical impacts, the impact velocity and the vertical velocity change are usually the same except for aircraft rebound. Rebound produces a velocity in the opposite direction which results in the total vertical velocity change being larger than the impact velocity.

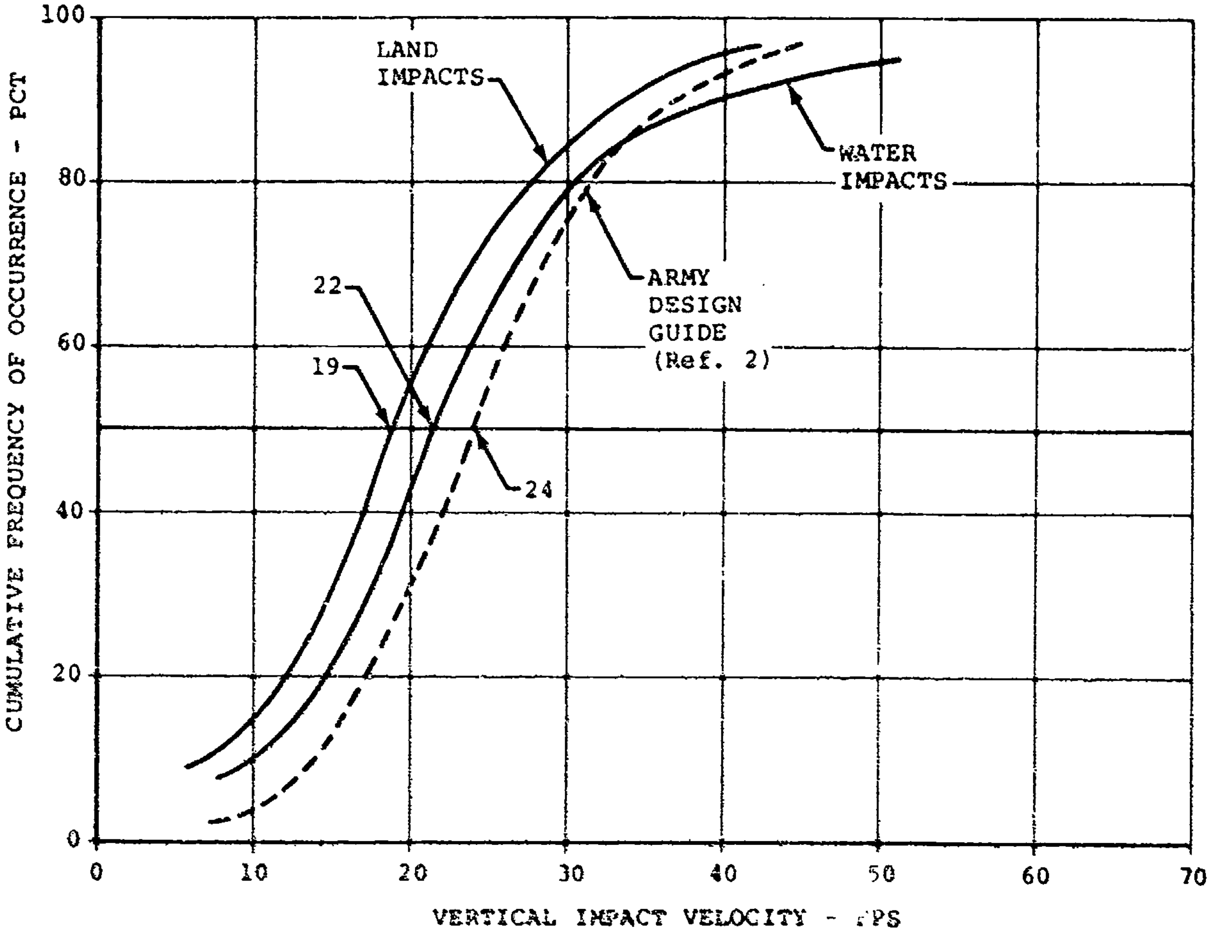


Figure 15. Cumulative Frequency Curves for Vertical Impact Velocities in Survivable Navy Helicopter Crashes.

Combined Helicopter Impact Velocities

Figures 16 and 17 show points which are the estimated vertical and longitudinal impact velocities of Navy helicopters in serious but survivable accidents. Figure 16 is for water impacts and Figure 17 is for land accidents. The figures are divided into three regions: survivable, marginally survivable, and

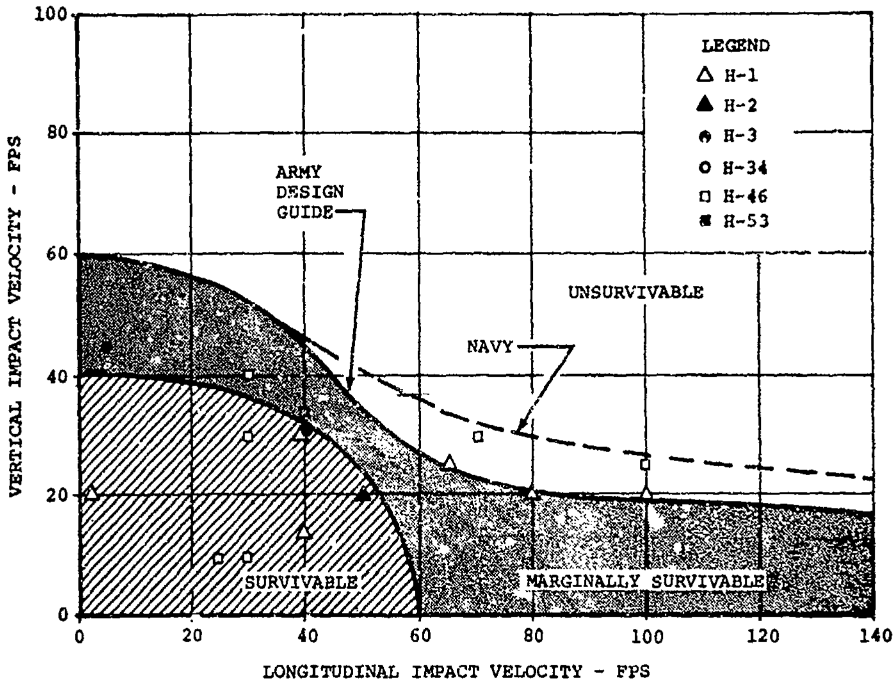


Figure 16. Combined Impact Velocities for Navy Helicopters in Survivable Water Impacts (January 1969 through May 1971).

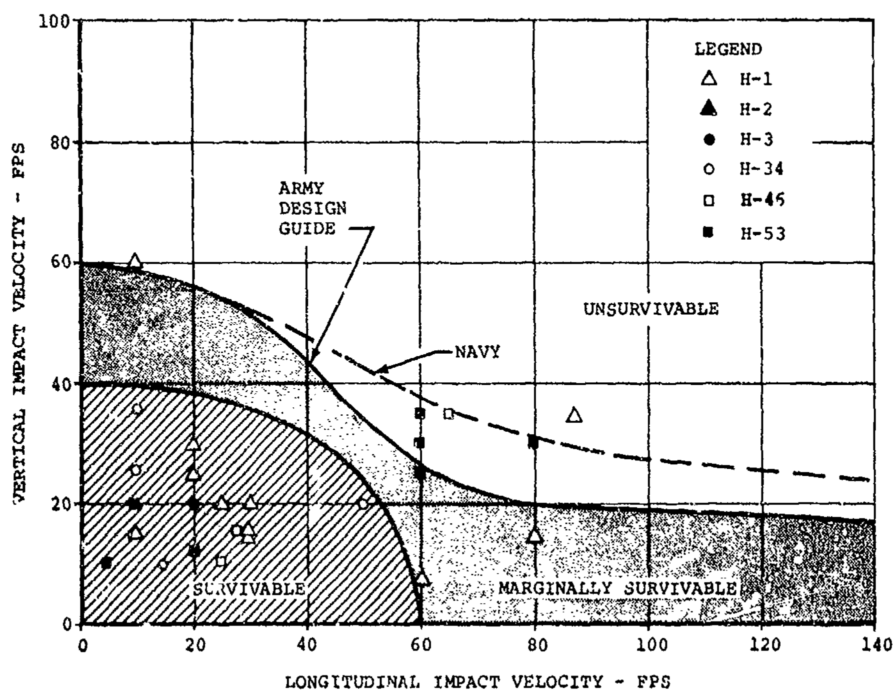


Figure 17. Combined Impact Velocities for Navy Helicopters in Survivable Land Impacts (January 1969 through May 1971).

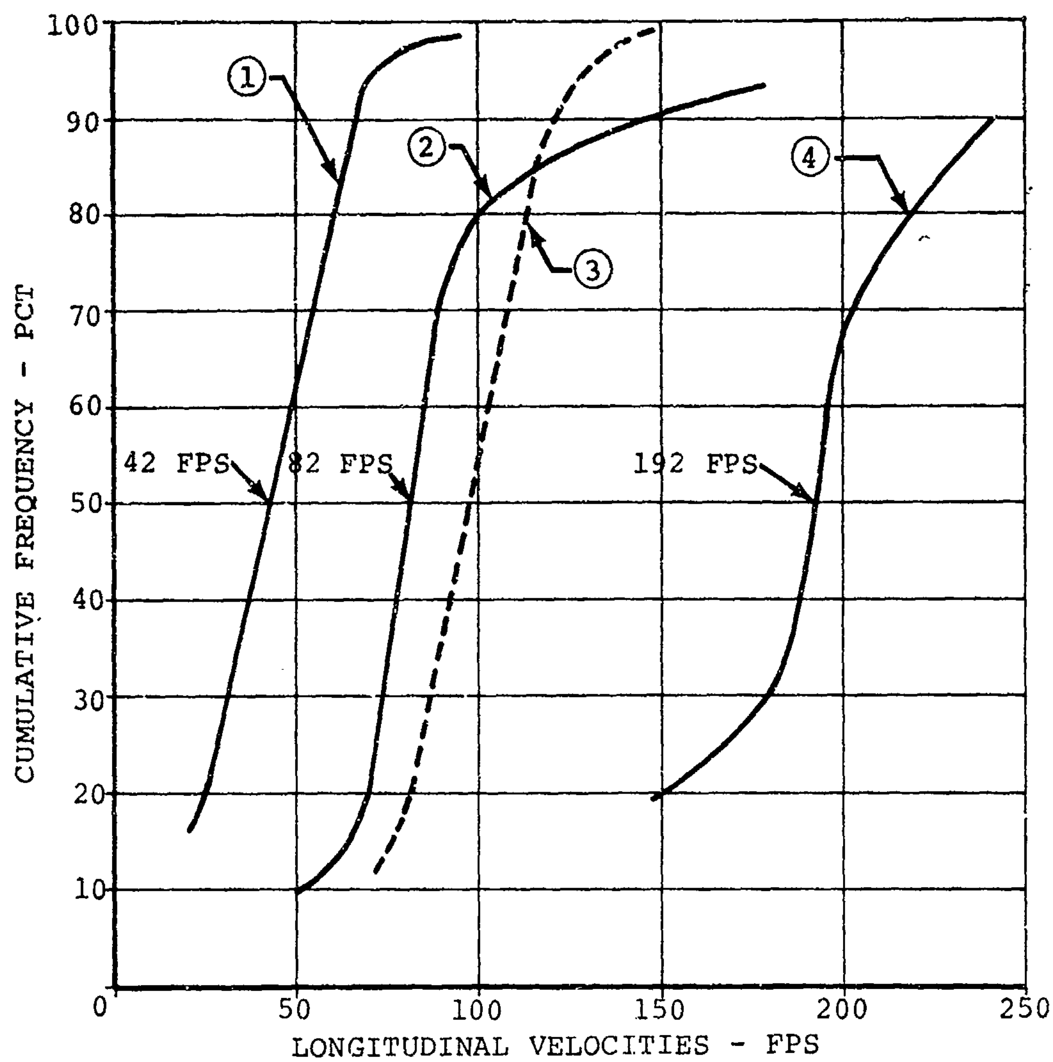
unsurvivable. This division is taken from the Army Crash Survival Design Guide and is based on survival histories of occupants in past military and civilian aviation accidents. It is noteworthy that several Navy helicopter accidents were survivable in the previously unsurvivable region of the figures. Most of these accidents which fell in the previously unsurvivable area were in either H-46 or H-53 models which are two of the Navy's newer helicopters.

The purpose of the corresponding curve in the Army Design Guide was to give the designer a feel for the magnitudes of impact attitudes and velocities which an aircraft should be designed to withstand without completely collapsing. Because of the Navy survival history, it is suggested that the marginally survivable region be expanded according to the dotted line which is superimposed on the curves. Aircraft designers should take these factors into consideration when designing future aircraft.

Fixed-Wing Velocities at Impact

The limited data from the survey were used to develop cumulative frequency curves for longitudinal velocities in survivable impacts of Naval jets and fixed-wing transport and patrol type aircraft. The curves are shown in Figure 18. There were insufficient data to develop separate curves for land and water impacts. Most were land or flight deck accidents since severe water impacts for fixed-wing aircraft accidents are usually unsurvivable.

Also included in Figure 18 are curves which would probably approximate the velocity change in the major impact pulse for fixed-wing transport and jet aircraft. The curve for the fixed-wing transport aircraft is taken from the Crash Survival Design Guide.[2] The dotted curve is a possible longitudinal velocity change curve for survivable Naval jet accidents. It is based upon the following assumptions: (1) that the shape of the curve



1 DESIGN GUIDE LONGITUDINAL VELOCITY CHANGE FOR SURVIVABLE FIXED-WING TRANSPORT ACCIDENTS

2 IMPACT VELOCITIES FOR SURVIVABLE NAVAL TRANSPORT AIRCRAFT ACCIDENTS

3 POSSIBLE VELOCITY CHANGE CURVE FOR SURVIVABLE NAVAL JET ACCIDENTS

4 IMPACT VELOCITIES FOR SURVIVABLE NAVAL JET ACCIDENTS

Figure 18. Cumulative Frequency Curves For Longitudinal Impact Velocities And Velocity Changes For Naval Jets and Fixed-Wing Transport Aircraft.

is similar to the other curves on the figure; (2) that the slope of the central portion of the curve is similar to the slope of the jet velocity curve, as were the velocity and velocity change curves for fixed-wing transports; and (3) that the median velocity change is probably about half the median impact velocity, as was the case for fixed-wing transports.

For the vertical direction, the velocity and velocity change may be assumed to be the same. Figure 19 shows vertical impact velocities for survivable Naval fixed-wing transport and jet aircraft accidents. The figure also shows the curve for fixed-wing transports as shown in the Crash Survival Design Guide.[2] There is virtually no difference between the two fixed-wing transport curves up to the 70-percent level. Above this level, the Navy curve flattens out. This may be due to the limited number of cases included in the Navy curve in comparison to numerous cases used to evolve the Army curve. The figure shows that Naval jets have nearly the same vertical velocities at impact as do fixed-wing transport aircraft. Comparison with Figure 15 indicates that jet and transport aircraft have much lower vertical impact velocities than helicopters.

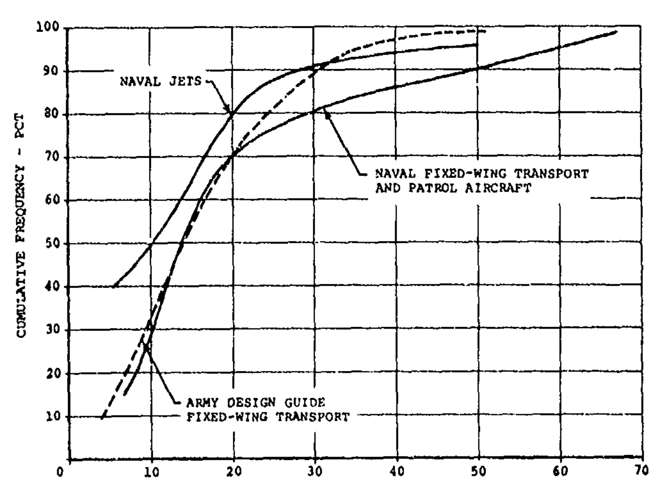


Figure 19. Vertical Impact Velocities for Survivable Fixed-Wing Transport and Jet Aircraft Accidents. (Naval Aviation, January 1969 through May 1971).

GENERAL COMMENTS

Photographs of crash-damaged Naval aircraft are used in this section to illustrate specific points relative to the crashworthiness of the aircraft.

Figure 20 shows an F-4 which caught fire in the fuel area. The heat from the fire caused the shrinkage crack at the left side of the figure just behind the cockpit section. This illustrates the reasoning behind the suggestions made by NAF El Centro personnel concerning the need for a heat shield between the cockpit and the fuel tanks to allow occupants more time to escape in case of fire.

Figure 21 shows how easily a spinning rotor blade can cut through the skin of a helicopter. It also shows the need for a number of escape hatches in the event some are rendered unusable; this happened in this accident.

Figure 22 shows an H-46 which impacted tail first (top view). When the nose section hit the ground, the transmission was torn loose, causing the cockpit to separate (bottom view). This figure illustrates the importance of a strong support structure for heavy components such as engines, transmissions, and rotor masts in helicopters. Figure 22 also indicates the need for strong framing members around doors and other fuselage openings.

Figure 23 graphically illustrates the reasoning behind some of the crashworthiness principles advocated by DeHaven[1] and others since the early 1950's. The figure shows two views of the OV-10A, one of the newer aircraft in the Navy inventory. The top view, a drawing, shows the original configuration of the aircraft which has twin-engines, a high wing, and twin booms with a horizontal tail surface between them. The cockpit is suspended forward and below the majority of the mass which is concentrated

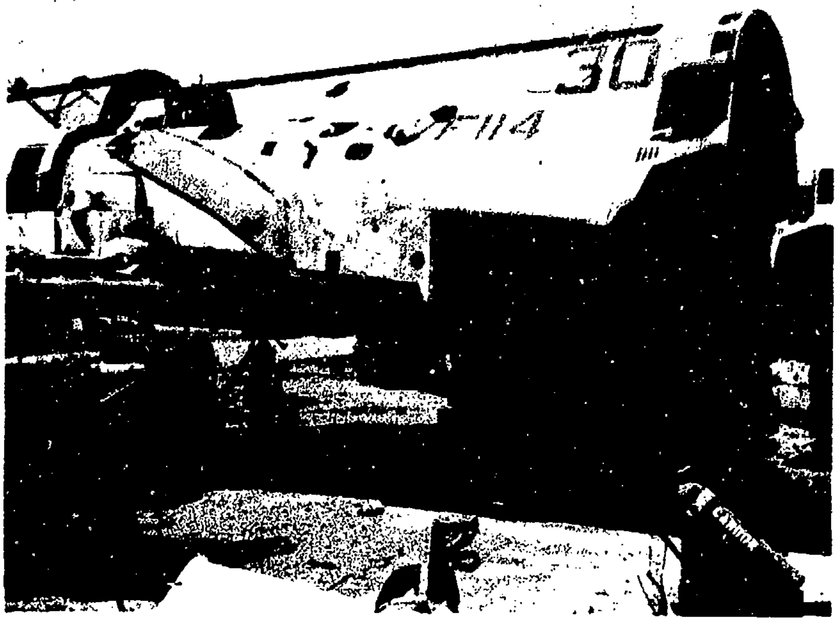


Figure 20. Fire Damaged F-4 Fighter Aircraft.

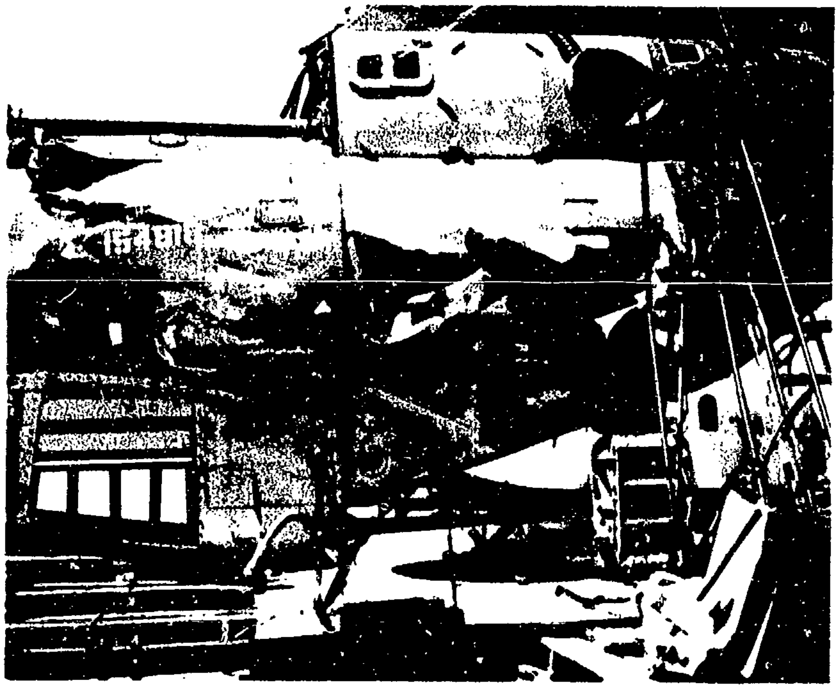
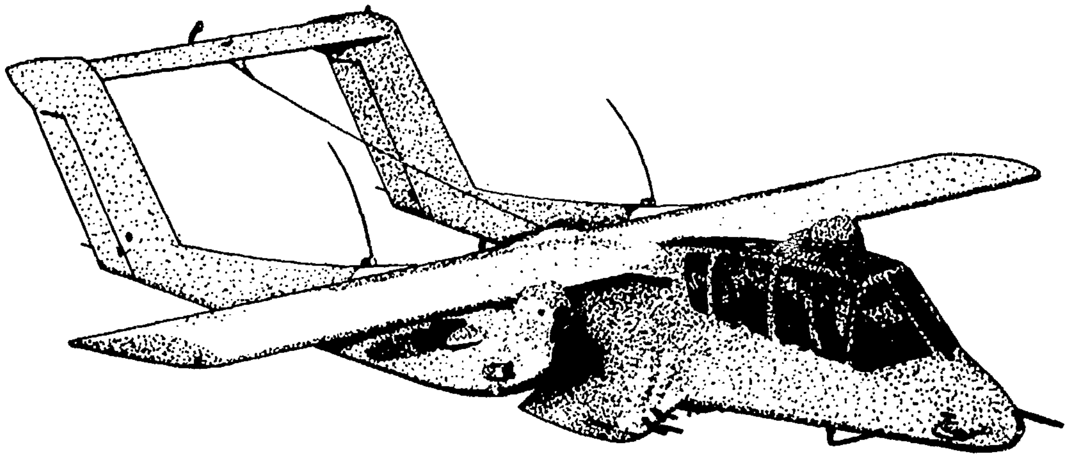


Figure 21. Helicopter Rotor Blade Damage to CH-46D.

A. Rear View

B. Front View

Figure 22. Two Views of a Crash-Damaged CH-46D Helicopter After a Tail First Impact.



A. OV-10A Original Configuration

B. OV-10A after Crash

Figure 23. Crashworthiness of OV-10A

in the engines and wing. The bottom view is a photograph of the remains of an OV-10A aircraft that crashed near San Diego, California. The nearly intact wing of the aircraft is inverted at the bottom of the photograph. The center of the photograph shows where the cockpit pod was originally located. The cockpit pod was totally destroyed as it crushed to absorb the energy of the crash.

It should be noted that the OV-10 was designed for maximum pilot visibility in all directions. This was accomplished in the design, and it may have been the only valid configuration after all other options were considered. The crashworthiness principles, however, which are violated in the aircraft design are:[7]

1. Locate the cockpit/cabin as far aft as possible in the fuselage and provide a large amount of energy-absorbing structure ahead of the occupants.

2. Design the cockpit/cabin area as the strongest part of the fuselage ("island of safety") in order to maintain the occupant's environmental integrity until the energy-absorbing action of surrounding structures is exhausted ~~in~~ progressive collapse.

3. Locate all heavy components below and forward of the cockpit/cabin to prevent crushing of the occupiable area by inertial loads.

CONCLUSIONS

The study reported herein has identified crashworthiness and shortcomings which exist in present Naval aircraft. Problem areas have been discussed and possible solutions suggested. This section reiterates some of the more important findings.

Future research in the field of Naval aircraft crashworthiness would be more fruitful if the present Aircraft Accident Report form were revised to include requests for specific data items concerning crash kinematics and structural deformations of the aircraft from which decelerative loads could be estimated. Impact velocities for Naval aircraft crashes estimated from narrative information agreed reasonably well with those reported in the Army's Crash Survival Design Guide.

The conclusion is made that Naval rotary-wing aircraft provide the highest potential for improvement in crash survival because more Naval personnel are involved in helicopter crashes than in fixed-wing crashes. More persons are injured in helicopter accidents and more fatalities occur in survivable helicopter accidents than in fixed-wing aircraft. This is primarily due to the lack of airborne escape systems in helicopters; however, many things can be done to protect the occupants in the event of a crash.

A great majority (nearly 80 percent) of the fatalities that occurred in survivable Navy helicopter accidents were due to causes other than impact forces exceeding human tolerance. Half of these fatalities were due either to drowning or loss at sea and nearly one-fourth were due to fire. There are two main factors which contribute to the large number of helicopter drownings. The first is the number of head, leg, and arm injuries which are caused by impact with strike zone objects and leave the occupant unable to rapidly egress the aircraft. The second factor is the tendency of helicopters to roll in water as soon as the rotor blades have stopped turning. In an inverted helicopter, escape hatches are hard to find and hard to dive through because of the buoyancy of some present life vests even when they are uninflated. Minor injuries also cause many of the thermal fatalities by slowing the egress of the occupants, but the major factor is the lack of crashworthy fuel systems in these aircraft.

Navy, Army, and Air Force injury patterns all reveal a prevalence of head, arm, and leg injuries, indicating a need for improvement of the state of the art in restraint systems, helmets, and padding. Improvement in seat retention is also important because many times this is the weak link in the tiedown chain, especially in accidents involving at least a moderate longitudinal velocity component. The results of this study indicate that there is a higher incidence of leg injuries in Naval aircraft crashes than in Army and Air Force crashes. This is partially caused by present restraint systems which provide no motion restriction for the legs and partially because seats come loose and allow the occupant's legs to come in contact with aircraft structure. Rudder pedals also cause many injuries to the legs and feet of pilots.

Rotor blade strikes and transmission intrusion into occupiable space account for fewer injuries and fatalities in Naval aircraft than in Army aircraft. This is especially true in the newer aircraft procured to the more stringest Navy specifications. Survivability in general is better in these newer Navy helicopters. Several of the H-46 and H-53 accidents were survivable with estimated impact velocities which fell into a region previously considered unsurvivable. Also, the location of the accident has a great effect on its survivability. Accidents which occurred on flight decks or runways had the lowest rates of fatalities per accident for attack, fighter, helicopter, and cargo aircraft. This is partly due to the fact that many of these accidents were less severe than others since they were normally take-off and landing accidents at correspondingly lower speeds and impact angles. The low rates are also due to the proximity of rescue and fire-fighting crews as well as immediate medical attention. Accidents in which the aircraft impacted water or trees were the most likely to produce fatalities.

The high energy content of a crashing jet aircraft results in most severe crashes being non-survivable. The occupants are placed in front of the great majority of the mass with virtually no crushable material in front of them. Consequently, ejection seats are the most feasible means of saving lives when an accident becomes inevitable in a high-performance jet aircraft.

In patrol and transport aircraft accidents, occupants who are helmeted, restrained, and seated in rear facing seats in the aft portion of the aircraft are more likely to survive. In one particular EC-121M accident studied, all survivors were in rear facing seats. A rear facing seat provides the best load distribution for the impact forces of a longitudinal crash.

The final conclusion is that research of this type, which points out the existing problems relating to crash survivability and structural performance of present day aircraft, will lead to more crashworthy aircraft in the future. More crashworthy aircraft will lead to a savings in lives and the money invested in training of the personnel.

RECOMMENDATIONS

On the basis of the findings of this report, the following recommendations are made:

- To generate and collect data essential to crashworthy design refinement, the present Navy Aircraft Accident Report form should be revised to include specific requests for impact variables and structural deformation data.

- To reduce the injury potential of Naval helicopters, these aircraft should be analyzed to establish needed changes in component locations, seat and restraint system design and tie-down, application of padding, and helmets.

- To extend emergency egress time, provisions should be made for the implementation of crashworthy fuel systems for all aircraft and for temporary flotation capabilities and anti-roll stability for helicopters involved in over-water flight.

- To generally upgrade crashworthiness of the aircraft, improvement should be made in cargo tie-down provisions, instrument mountings, and ancillary equipment installations.

- To encourage the use of safety equipment such as restraint systems and helmets, the equipment should be designed with special care to ensure that the resulting item is easy to use and comfortable.

- To improve survivability in aircraft not procured to Navy specifications, the Navy should insist that the manufacturers reinforce key components, such as transmission and engine mounts, to meet the Navy specifications.

- To improve survivability in future aircraft, special care should be taken in the design stages for the provision of energy-absorbing structure below, to the side, and forward of the occupant compartments.

- To continue the progress made in this study, more research should be done in the future, hopefully with more complete information provided by an improved Aircraft Accident Report Form.

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13. ABSTRACT

~~This~~ report contains the results of research in survival aspects of Naval aircraft crashes. The study was made to identify areas for needed improvement in structural design. A literature study, documented crash data, and firsthand data obtained in interviews with Naval personnel and in visits to Naval facilities established a data base which was used to identify the Naval aircraft crash environment and crash survival problems. The study ~~showed~~ a need for modification ~~of~~ the Naval Aircraft Accident Report form ~~to~~ include requests for specific impact variables. It also ~~showed that~~ Naval helicopters are ~~the most fruitful~~ area for ~~future efforts aimed at~~ crashworthiness improvement.

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